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EnviroFish, Version 1.0: User's Manual

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Final report

Abstract: EnviroFish is both a modeling approach and a computer software. As a modeling approach, EnviroFish estimates the value of floodplain habitat suitable for fish reproduction under a given set of hydrologic and hydraulic conditions. As a software, EnviroFish is a Java computer program facilitating the application of the modeling approach. This manual describes both the modeling approach and the software.

The EnviroFish approach integrates hydrology, hydraulics, land use, and empirically based knowledge of fish reproductive strategies in riverine floodplains to predict a biological response to different flooding scenarios suitable for standard federal planning processes. EnviroFish can be used to calculate Habitat Units for specific floodplain habitats, with each habitat providing different values for spawning and rearing fishes. In order of least to most preferred habitats, are agricultural fields, fallow fields, bottomland hardwood forests, and floodplain waterbodies. EnviroFish was initially developed for flood control projects in the lower Mississippi River Valley. However, the approach is applicable to any alluvial river system where floodplain fish spawning habitat is being managed, mitigated, or restored, by determining applicable land use categories and HSIs for representative fish species.

The EnviroFish software is designed to directly accept data in the Corps of Engineers Data Storage System (DSS) file format. EnviroFish calculates ADFA for an array of project alternatives. The user specifies values of hydraulic criteria (flooding depth and duration) for successful spawning and rearing of fishes and also specifies land use categories to calculate ADFA.

This *User's Manual* discusses the biological basis of EnviroFish, elements of the model, using the software, application considerations, and an example problem.

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Preface

This work was performed by the U.S. Army Engineer Research and Development Center (ERDC) in cooperation with the U.S. Army Engineer District, Vicksburg (MVK) and the U.S. Army Engineer District, Memphis (MVM). The original version of *EnviroFish* was written in FORTRAN by Ron Goldman, Basil Arthur, and Charlie McKinnie, MVK, based on input from Dr. Jack Killgore and Dr. Jan Hoover, ERDC, and Gary Young, MVK, on hydrologic and hydraulic criteria for floodplain spawning fishes. Under the supervision of Kent Parrish and Dave Johnson, MVK, *EnviroFish* was revised by Don Johnson, MVK, and written in JAVA. Andy Casper, ERDC, assisted in initial development of the *User's Manual*. Barry Bruchman and Dr. Robert Hunt (MVM), and Dr. L. Yu Lin, Christian Brothers University, wrote the final version of the User's Manual chapters for running and applying EnviroFish including figures and tables. Final development of the software was conducted under the supervision of Dr. L. Yu Lin, Professor of Civil Engineering, Christian Brothers University, Memphis, Tennessee.

Funding was provided by the U.S. Army Engineer Districts, Vicksburg and Memphis, the System-wide Water Resource Program, and the Ecosystem Management and Restoration Research Program at ERDC.

This work was performed under the general supervision of Dr. Tim Lewis, Chief, Aquatic Ecology and Invasive Species Branch, Environmental Lab (EL), Drs. David J. Tazik and Edmond Russo, Chief, Ecosystem Evaluation and Engineering Division, EL, and Dr. Elizabeth C. Fleming, Director, EL. COL Kevin J. Wilson was Commander of ERDC. Dr. Jeffery P. Holland was Director.

EnviroFish software and accompanying programs (HEC DSSVue, example .dss file) can be downloaded at the following site: http.el.erdc.usace.army.mil/products.cfm?Topic=model&Type=other .This report should be cited as follows:

Killgore, K. J., B. Bruchman, R. Hunt, L. Lin, J. J. Hoover, D. Johnson, D. Johnson, G. Young, K. Parrish, R. Goldman, and A. Casper. 2012. *EnviroFish Version 1, User's Manual*. ERDC/EL TR-12-19. Vicksburg, MS: Engineer Research and Development Center.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters

1 Introduction

EnviroFish is both a modeling approach and a computer software. As a modeling approach, EnviroFish estimates the value of floodplain habitat suitable for fish spawning and rearing under certain hydrologic and hydraulic conditions. As a software, EnviroFish is a Java computer program facilitating the application of the modeling approach. This manual describes the modeling approach of EnviroFish and serves as a user's manual for the software.

EnviroFish integrates the needs of reproducing fish with the reproductive opportunities afforded by a flooded landscape, as shown in Figure 1-1. To the upper left of Figure 1-1, fish requirements are reflected by a reproductive strategy of fishes in riverine floodplains and the values of different land uses for spawning and rearing. To the upper right of Figure 1-1, reproductive opportunities at a project site are reflected by the hydrology, hydraulics, and land uses present. The integration of requirements and opportunities is reflected in average daily flooded area (ADFA) by land use category type. The ADFA, when multiplied by a weighting index (Habitat Suitability Index), culminates in a consolidated measure of habitat for the project landscape as a whole, expressed in Habitat Units (HUs). The response variable, HUs, allows Habitat Evaluation Procedures (HEP) to be used to complete the analysis of project alternatives (USFWS 1980). This approach can be used to assess whether a flood control alternative, restoration / mitigation activity, or another water allocation decision would have positive or negative effects on floodplain fish habitat. Different alternatives can be compared during project planning; this is consistent with standard Army Corps of Engineers policy.

EnviroFish has been applied in the planning of Corps of Engineers flood control projects in the lower Mississippi River Valley, and continues to be refined and updated. However, the approach is applicable to any alluvial river system where floodplain fish spawning habitat is being managed. EnviroFish was developed over a 15-year period, beginning in the early 1990s, to predict a quantitative response by the fish assemblage to altered flood regimes. EnviroFish can be used to predict changes in functional reproductive habitat over large or small geographic areas. There is no limit to the size of the project area, if suitable hydraulic and land use data are available or can be synthesized.

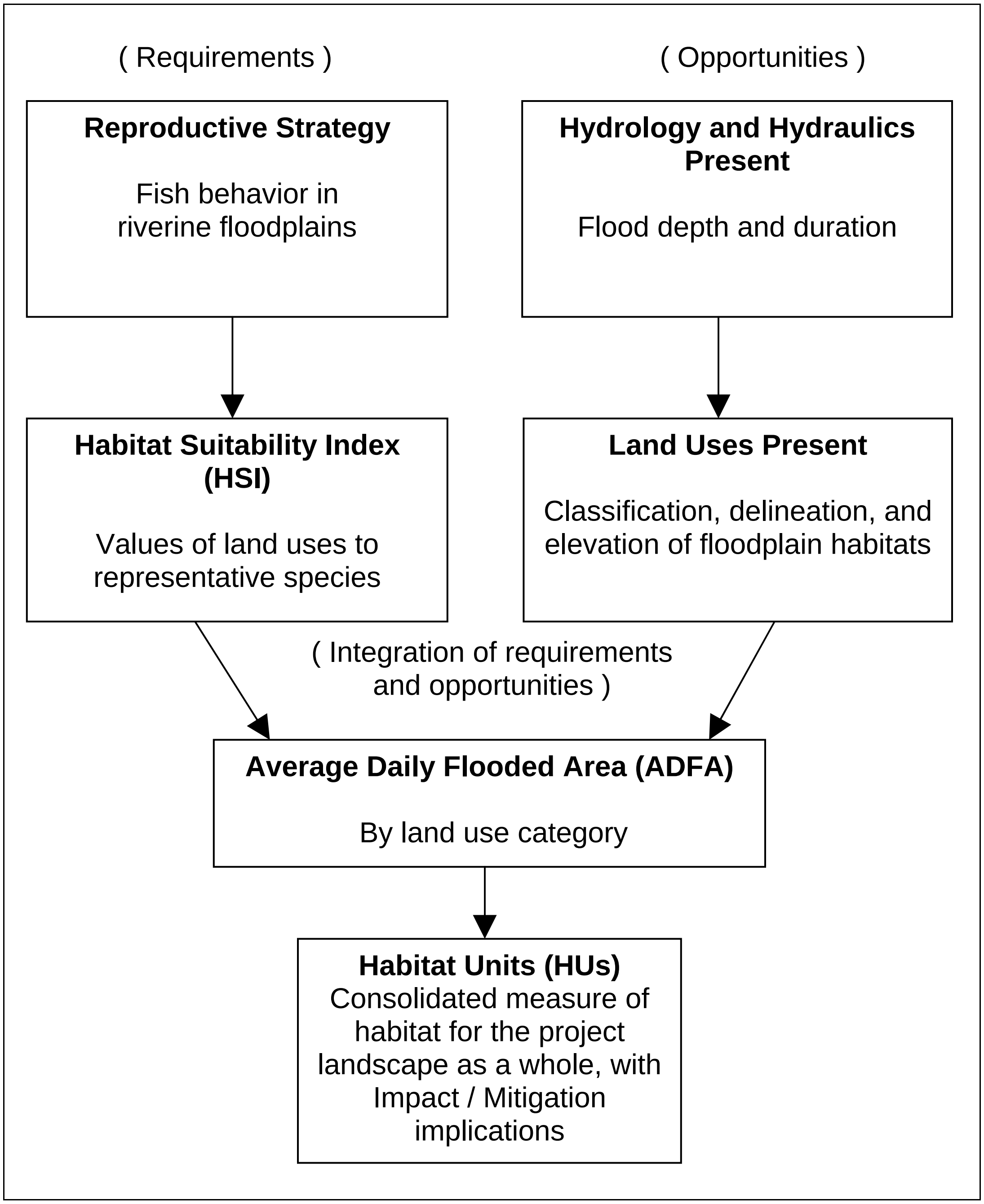


Figure 1-1. Flow Chart of the EnviroFish Approach Culminating in Quantification of Habitat Units for a Project Landscape.

Purpose

The purpose of this manual is to describe the background and approach of modeling fish spawning and rearing habitat in floodplains. This manual makes this approach available to a wide range of stakeholders drawn from government, academia, environmental organizations, and the communities for which water resources and environmental projects are planned.

Approach

The EnviroFish method may be outlined according to its modeling approach and its software characteristics. As a modeling approach, EnviroFish:

1. applies knowledge regarding fish spawning and rearing requirements to the evaluation of reproductive opportunities afforded over time and space in a project landscape;
2. assigns values to different land uses for fish spawning and rearing;
3. quantifies the elevation vs. area relationships of different land uses in a project landscape;
4. quantifies the effects of land use change;
5. quantifies the effects of climatic variability;
6. quantifies the effects of proposed project alternatives; and
7. quantifies the effects of operational modifications to project alternatives.

As a software, EnviroFish:

1. is coded in a current programming language facilitating its continued development and dissemination;
2. uses a proven, well-documented, and widely used water resources database management software, the Corps of Engineers Data Storage System (DSS); and
3. runs in a user-friendly windows format familiar to users.

Scope

The *User's Manual* focuses on how the body of knowledge regarding fish spawning and rearing has supported the development of modeling concepts that can be applied in computer software to realistically characterize project situations. The software calculates Average Daily Flooded Area (usually in acres). Weighting of these acres using Habitat Suitability Index values to calculate Habitat Units must be done in a spreadsheet external to the EnviroFish software. The Habitat Index Suitability values used in the analysis must be developed specifically to represent the habitats and fish species being assessed in the project area. The material in the manual is not a substitute for the professional knowledge and experience in fish biology required to appropriately plan an EnviroFish analysis. Preparation of input to the model requires the services of hydrologists, hydraulic engineers, biologists, and Geographic Information Systems (GIS) specialists.

Organization of the *User's Manual*

The following chapters present a detailed explanation of the EnviroFish approach and software. Chapter 2 explains the biological basis of EnviroFish. Chapter 3 provides a detailed description of the mechanics of the EnviroFish spawning and rearing habitat analysis. Chapter 4 introduces the use of the EnviroFish software and describes the input required. Chapter 5 describes EnviroFish software output. Chapter 6 discusses application of EnviroFish to various situations. Chapter 7 presents an example of EnviroFish use.

2 Biological Basis

The biological basis of EnviroFish follows the HEP (USFWS 1980). In the HEP framework, Habitat Units (HUs), calculated by multiplying a Habitat Suitability Index (HSI) value ranging from 0.0 (unusable habitat) to 1.0 (optimum habitat) by a measurement of area (e.g., acres of flooded bottomland hardwood), express the quality and quantity of fish habitat for different project plans. The fundamental assumption is that the abundance and distribution of the fish species or group of species being modeled respond in a predictable fashion to changes in quality and quantity of habitat. However, for a variety of reasons unrelated to habitat (disease, exploitation, population cycles), changes in HUs may not always affect population density of fish in an area. A more current perspective is that areas with higher quantity and quality of HUs are assumed to have greater potential to support more fish than areas with lower HUs.

The reproductive cycles of most floodplain fishes are closely related to timing, spatial extent, and duration of flooding. Numerous fish species undergo regular migrations to use inundated floodplains for a variety of reproductive purposes such as spawning, short-term incubation of eggs, and eventually as nursery habitat for yolk-sac (non-feeding) larvae (Guillory 1979, Ross and Baker 1983, Finger and Stewart 1987, Copp 1989, Scott and Nielson 1989). Once the yolk-sac is absorbed, larval fish must forage in the floodplain or adjacent waterbodies for small insects and zooplankton (Lietman et al. 1991). These early life history stages are often the limiting factor in population growth, and inter-annual variations in flooding regime of rivers affect reproductive success and year-class strength of many species (Starrett 1951, Guillory 1979, Larson et al. 1981; Zeug 2005).

EnviroFish was developed to quantify the importance of seasonally inundated floodplains as well as floodplain waterbodies such as oxbow lakes during periods of increased energetic needs for reproduction and growth of healthy fisheries (Benke et al. 2000; de la Cruz 1978; Lambou 1990; Miranda 2004; Ward et al. 1999; Whitaker 1977). EnviroFish characterizes the hydraulic environment of the floodplain in terms of water depth and duration of flooding. Fish move onto the floodplain during rising elevations to exploit additional food resources and spawning sites. Lateral movements of adult fish on the floodplain, however, can decrease exponentially with reductions in water surface elevation (Kwak 1988). Spawning failure may

occur if water levels remain low and population numbers are high (Starrett 1951). However, those waterbodies that are connected to main river channels, either continuously or during floods, could function as important fish nursery areas (Beecher et al. 1977; Dewey and Jennings 1992; Hoover et al. 1995). EnviroFish is designed to track changes in functional floodplain habitat as water elevations are modified or controlled. In addition, EnviroFish can be used to track the annual variation in flooded habitat, providing an average over a selected period of record.

Defining Fish Reproductive Criteria

EnviroFish calculates the area of functional floodplain habitat in terms of fish spawning or rearing. Specific rules were established to describe spawning versus rearing. Floodplain spawning habitat is area available for the deposition and incubation of eggs. Spawning habitat is delineated hydraulically in the model; water depth and duration are user-defined variables in the computer model. For example, minimum water depth for spawning can be set to 1-foot below a water surface, and duration could be at least 8 days. A minimum water depth of 1 foot allows adults to access shallow, flooded areas; depths less than 1 foot may impose physical limitations in the spawning process and greater risk of predation. Flood duration of at least 8 days ensures that suitable time is allowed for nest construction and other spawning activities by the adults. Shorter flood durations may result in the eggs becoming stranded and desiccated if water recedes too quickly. The minimum 1-ft deep, 8-day duration rule is considered a conservative value to delineate spawning requirements for most warmwater fish species found in the Mississippi River basin (Breder and Rosen 1966; Carlander 1969; Carlander 1977; Becker 1983; Robison and Buchanan 1988). This rule guarantees an effective spawning window, emphasizes longer development times, and provides a margin for temporal variation in spawning activities (adult movement onto the floodplain, nest construction and guarding, dispersal of fry). However, these are only examples and the user is responsible for parameterizing the model.

Once hatched, rearing fishes (including yolk-sac and post yolk-sac larval phases) can potentially use any area of the inundated floodplain regardless of flood depth and duration, although a minimum depth of 0.1 feet or more can be applied to satisfy physical limitations. However, during falling elevations of a flood, EnviroFish provides an option to restrict larval fish habitat to the minimum user-defined water depth. This rule assumes that larval fish will move with the receding water and not utilize the shallow

(<1 ft), temporally inundated lands; otherwise, fish may become stranded or highly susceptible to predation.

Delineating the Boundaries of the Functional Floodplain

In an EnviroFish analysis, functional floodplain refers to inundated areas available for fishes to use in spawning and rearing. The boundaries of the functional floodplain can be limited by defining an upper elevation beyond which the usability and functionality of the floodplain is diminished. If an upper limit is established in EnviroFish, flooded area above this elevation will not be considered in average daily flooded area (ADFA) calculations. The elevation-area table in DSS must be revised to establish an upper limit to the functional floodplain. Any flood frequency can be used in the EnviroFish software to establish an upper limit if suitable biological, land use, and gage data are available.

An example is the designation of the 2-year frequency flood elevation. This flood frequency could be justified according to the following reasons:

1. Most fish species reach sexual maturity at an age of 1 or 2 years. Since the 2-year flood is the flood with a 50% annual chance of exceedance, the 2-year flood is sufficiently frequent to affect the first reproductive season of a significant fraction of individual fish of the species under consideration. Moreover, the life span of small-sized species is only 2-3 years, and some may only reproduce once. Thus, the floods larger and less frequent than the 2-year flood — although not harmful — are not events that short-lived fish can generally benefit from. Larger-sized species can live up to 10 years, and, in riverine floodplains, are exposed to high and low flood elevations on an annual basis. For these longer-lived species, the more extreme floods may result in higher fish abundance, but do not represent flooding regimes that maintain baseline population levels over the life of most projects (i.e., a 50-year project life).
2. In agricultural landscapes, lands that are flooded less frequently than those inundated by a 2-year flood are mostly unsuitable as reproductive habitat for two reasons. First, the floodplain closest to the river provides immediate access to reproductive fishes undergoing spawning migrations. Fish may have to travel miles from the mainstem river to reach lands corresponding to a 3-year or greater flood frequency. Second, even if adults do move great distances to spawn, eggs deposited in cleared lands far removed from the mainstem river have a greater risk of becoming trapped in isolated pools during receding elevations.

Flood frequency elevation can be determined through hydrologic and hydraulic analysis as described in engineering publications such as *Hydrologic Frequency Analysis* and *River Analysis System User's Manual* (See Appendix A).

Habitat Types within the Functional Floodplain

Satellite imagery and other GIS information can be used to delineate floodplain habitats relevant to fish reproduction. In the lower Mississippi River Valley examples used as case studies, five habitat types were determined based on position (e.g., mainstem or floodplain), land use/vegetation type (e.g., agriculture, fallow field, bottomland hardwoods), permanence of water (e.g., oxbow lake), and elevation:

1. Seasonally inundated agricultural land
2. Seasonally inundated fallow and herbaceous marsh land
3. Seasonally inundated bottomland hardwoods
4. Oxbow lakes or other large (>1-acre) floodplain waterbodies seasonally connected to the mainstem river
5. Small, waterbodies (scatters, brakes, sloughs, and tributary mouths) seasonally connected to the mainstem river

Floodplain waterbodies are those that retain water during the reproductive season, but may become dewatered outside this seasonal window. Furthermore, floodplain waterbodies should be connected at least once during the reproductive season to provide access to adult fish that are undergoing spawning movements. Additional floodplain habitats can be delineated according to project- or site-specific needs and objectives. However, before adding new categories, the user must consider how well new land use categories can be delineated and whether corresponding HSI values exist for the species of interest or whether they can be determined.

Calculation of Area

EnviroFish calculates ADFA for a defined analysis period (e.g., 20 years), using historical or synthetically derived water surface elevations. ADFA incorporates variations in the hydroperiod (flood onset, depth, and duration) and is a realistic estimate of the flooding regime for a baseline condition and any number of project alternatives. If an acre is the unit of area selected for a particular application, one ADFA is equivalent to one acre of inundated land satisfying the depth/duration criteria for successful

spawning or rearing. In general, the magnitude of area satisfying depth/duration criteria is less than the total area of land inundated.

Selecting Habitat Suitability Index Values

To obtain HUs, HSI values need to be multiplied by ADFA for each land use category. HSI values must be determined for each project area to reflect characteristic fish assemblages and their affinity to different floodplain habitats. An example of HSI values combining spawning and rearing into one life stage is shown in Table 2-1. These values evolved from numerous applications of the model in the lower Mississippi River Valley and were initially developed by consensus of an interagency team of biologists (e.g., Delphi technique, Crance 1987), supplemented by published field data on fish reproduction in floodplains (Baker et al. 1991; Hoover et al. 1995; Killgore and J.A. Baker 1996; Hoover and Killgore 1998) and best professional judgment.

Table 2-1. Habitat Suitability Index (HSI) Values for Spawning and Rearing of Fishes used to Evaluate Riverine Floodplains of the Lower Mississippi River Valley.

Land use Category	HSI
Agricultural land	0.2
Fallow	0.5
Herbaceous marsh	1.0
Bottomland hardwoods	1.0
Large (>1 acre), floodplain waterbodies (e.g., oxbow lakes)	1.0
Small, floodplain waterbodies (e.g. scatters, brakes, sloughs)	1.0

The example HSI values for combined life history stages make at least three assumptions:

1. Larval fish utilize the same habitat as spawning sites, with one exception. Larval fish have smaller physical dimensions that allow access to more shallow (<1.0 ft) water than physically available for spawning needs (typically ≥ 1.0 ft depth, 8 days duration). The EnviroFish software provides considerable flexibility. User-defined minimum and maximum allowable depths for spawning or rearing may be input to accurately represent a specific situation. For spawning, EnviroFish user options are also available to control how falling or rising water surface elevations are treated on the spawning period days immediately following the day on which an egg is deposited in a nest. These options give the biologist more control in dealing with the possibility of larval fish becoming stranded if

water levels should drop too quickly or being swept downstream (Harvey 1989) and in dealing with larval preferences for deeper water where food and structure are plentiful.

2. The majority of species that spawn and rear in riverine floodplains are pre-adapted to structurally complex habitats such as bottomland hardwood wetlands (BLH). Therefore, cleared lands have less value for spawning and rearing. The example HSI values reflect this trend, with optimum conditions occurring for BLH (i.e., HSI = 1.0), intermediate values for fallow fields (HSI = 0.5), and the lowest value for cleared, agricultural lands (HSI = 0.2).
3. Similar to BLH, floodplain waterbodies are optimum (HSI=1.0) for spawning and rearing if the waterbody is periodically connected to the mainstem river during the reproductive season. This assumes that floodplain waterbodies provide adequate spawning substrates for egg deposition, and larval fish have high growth rates for survival in waterbodies that retain water during periods of early development.

The example HSI values represent a community-level perspective of the biological response of warmwater fishes to flooding in riverine systems. In most large floodplain river systems, this could encompass a very large assemblage of fish species. Characteristic fish species represented by this community-level model can be presented as a guild (Table 2-2 and Table 2-3). Species within a guild are assumed to share similar reproductive requirements. In this case, fish species in the lower Mississippi River Valley were grouped based on substrate used by spawning adults and characteristic habitat (channel vs. floodplain) used by larvae. For species that spawn and rear in floodplains, different substrates or structural conditions are preferred to deposit eggs or construct nests: vegetation, sand, and/or crevices. For these reasons, BLH and floodplain waterbodies have optimum HSI values because of their habitat heterogeneity. In addition, some species have floating eggs (i.e., pelagophils). Considering these multiple reproducetive strategies, at least four guilds with almost 50 species total could be influenced by changes in river elevations in the lower Mississippi River Valley, and these species are represented by the example HSI values. Guilds could be expanded if seasonal considerations (early, mid, and late spawners) and separate life stages (spawning versus rearing) were included (*sensu* Floyd et al. 1984; Mathews 1984). The user is responsible for selecting either a guild or individual species approach, as well as designating the appropriate HSI values.

Table 2-2. Guild of Warmwater Fish Species in the Lower Mississippi River Valley that Spawn and Rear Primarily in River Channels.

Pelagophils	Lithophils	Phytophils	Litho-Psammophils	Speleophils
Skipjack herring	Shovelnose sturgeon		Silverband shiner	Red shiner
Gizzard shad	Paddlefish		River carpsucker	Spotfin shiner
Threadfin shad	Quillback		Harlequin darter	Blacktail shiner*
Goldeye	Blue sucker		Logperch	Bullhead minnow
Mooneye	Northern hog sucker		Blackside darter	Bluntnose minnow
Plains minnow	Spotted sucker		Saddleback darter	Blue catfish
Silver chub	River redhorse		Dusky darter	Flathead catfish
Speckled chub	Golden redhorse		River darter	Channel catfish*
Emerald shiner	Shorthead redhorse			Freckled madtom
River shiner	White bass*			Tadpole madtom
Freshwater drum*	Yellow bass			Johnny darter
	Striped bass			
	Smallmouth bass			
	Sauger			
	Walleye			
	Chestnut lamprey			

Table 2-3. Guild of Warmwater Fish Species in the Lower Mississippi River Valley that Spawn and Rear Primarily in Floodplains.

Pelagophils	Lithophils	Phytophils	Litho-Psammophils	Speleophils
Mimic shiner*		Spotted gar	MS silvery minnow	Black bullhead
Channel shiner		Longnose gar	Ribbon shiner	Yellow bullhead
		Shortnose gar	Golden shiner	Pirate perch*
		Bowfin	Ironcolor shiner	
		Grass pickerel	Weed shiner	
		Chain pickerel	Pugnose minnow	
		Smallmouth buffalo*	Creek chubsucker	
		Bigmouth buffalo	Shadow bass	
		Black buffalo	Flier	
		Golden topminnow*	Green sunfish	
		Blackstripe topminnow	Warmouth	
		Blackspotted topminnow	Orangespotted sunfish	
		Banded pygmy sunfish	Bluegill	
		Mud darter	Longear sunfish*	
		Bluntnose darter	Redear sunfish	
		Slough darter	Redspotted sunfish	
		Cypress darter*	Spotted bass	
		Brook silverside	Largemouth bass*	
		Inland silverside	White crappie*	
			Black crappie	

Calculation of Average Annual Habitat Units

Average Annual Habitat Units (AAHUs) are Habitat Units annualized over the life of the project and are the last step in a series of data inputs and outputs to calculate a biological response to flooding over long time periods (Figure 2-1). Annualization is calculated according to the guidance of the HEP, and can be completed in a spreadsheet program outside of the EnviroFish software. AAHUs are calculated to reflect changes in land use (e.g., reforesting frequently flooded agricultural lands), construction impacts, and predicted longevity of project benefits. Changes in land use and construction impacts will alter the HSI value for specific acres of habitat over the project life. By calculating HUs for each year using the appropriate Average Daily Flooded Area derived from EnviroFish software and the HSI values, then summing the total HUs and dividing by the number of years over the project life, an accurate portrayal of the long-term biological response to floodplain alteration and management can be obtained. AAHUs can be compared among project alternatives, and applied to an incremental cost analysis to select the preferred alternative for any type of project (e.g., flood control, mitigation, restoration).

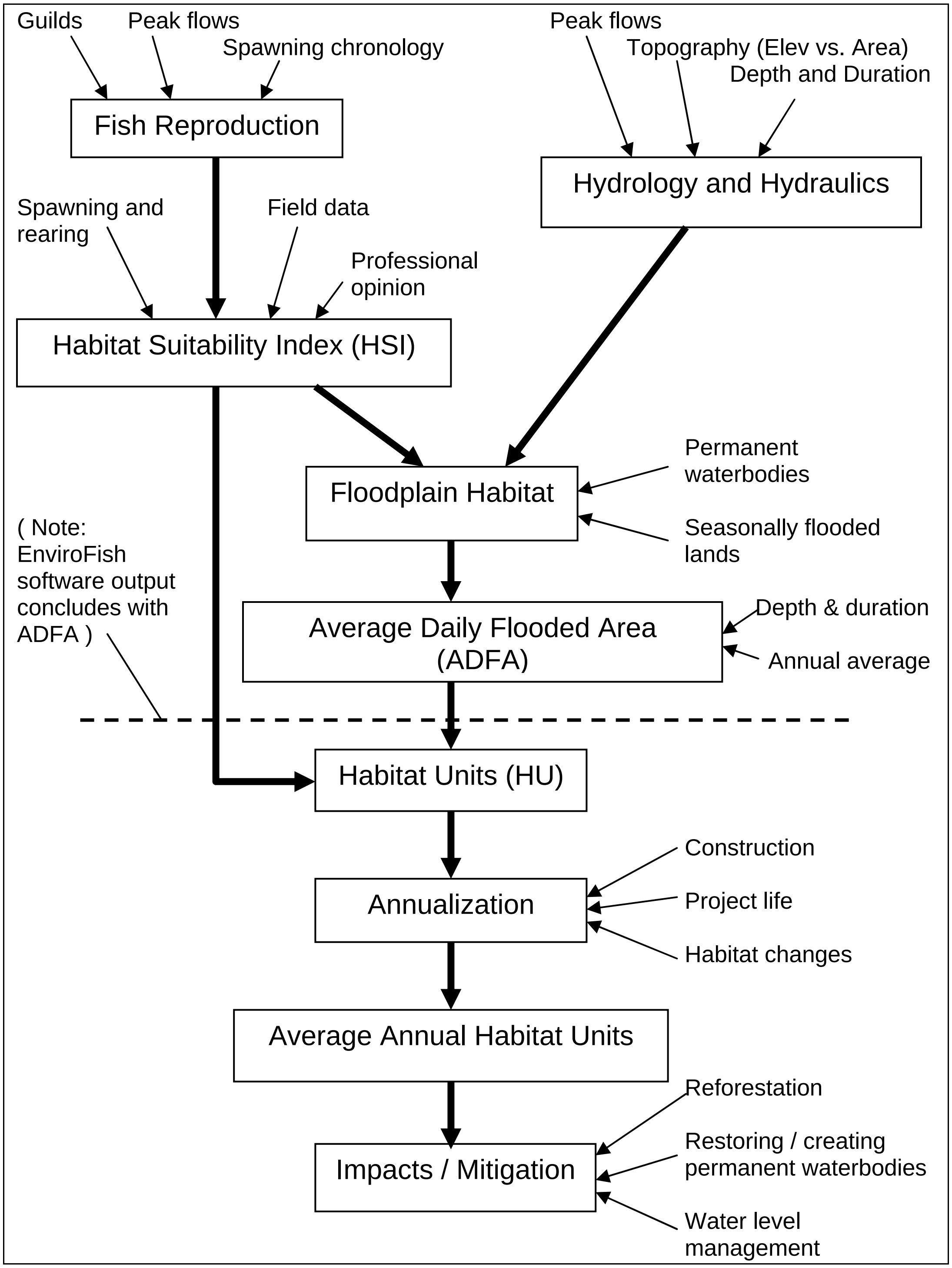


Figure 2-1. Flow Chart of EnviroFish Approach Culminating in Evaluation of Project Impacts and Mitigation.

3 Model Elements

This chapter presents six modeling elements of the EnviroFish approach. Based on input reflecting species selection, topography, land use, daily water surface elevations, and procedures for calculating spawning and rearing habitat areas, a measure of fish reproductive habitat area is determined for a landscape.

The EnviroFish software concludes output with an average daily flooded area for each land use over the multi-year analysis period. The comparative value of a given land use is represented by a weighting factor known as the HSI, which ranges from zero to unity. The product of ADFA and HSI is the measure of Habitat Units for a given land use within the landscape being evaluated. Habitat Units are calculated after completion of an EnviroFish program run. EnviroFish calculates ADFA, and these values can be copied to a computer spreadsheet to perform the Habitat Unit calculations. A flowchart of the overall approach is shown in Figure 3-1. Application of the modeling elements reflect both the variability of habitat suitability across a landscape as well as the variability of inundation within a single season, and across many years of spawning and rearing seasons.

Species Selection

An EnviroFish analysis estimates the habitat available for a single species of fish, or for a guild (or groups) of fish species that can be evaluated appropriately using the selected parameters. The inputs of spawning season, spawning period, limiting depths, and the value of land cover should be compatible with the habitat preferences and requirements of the species or guild selected.

Topography

The EnviroFish approach requires input describing the topography of the land subject to inundation. Topographic information facilitates determination of how much inundated land area satisfies the adopted habitat constraints for a given water surface elevation. Topography is characterized by a table of elevation vs. land area at and below a given elevation, which is equivalent to the area that would be flooded by a level pool of water at a given elevation. The areas listed in the table are

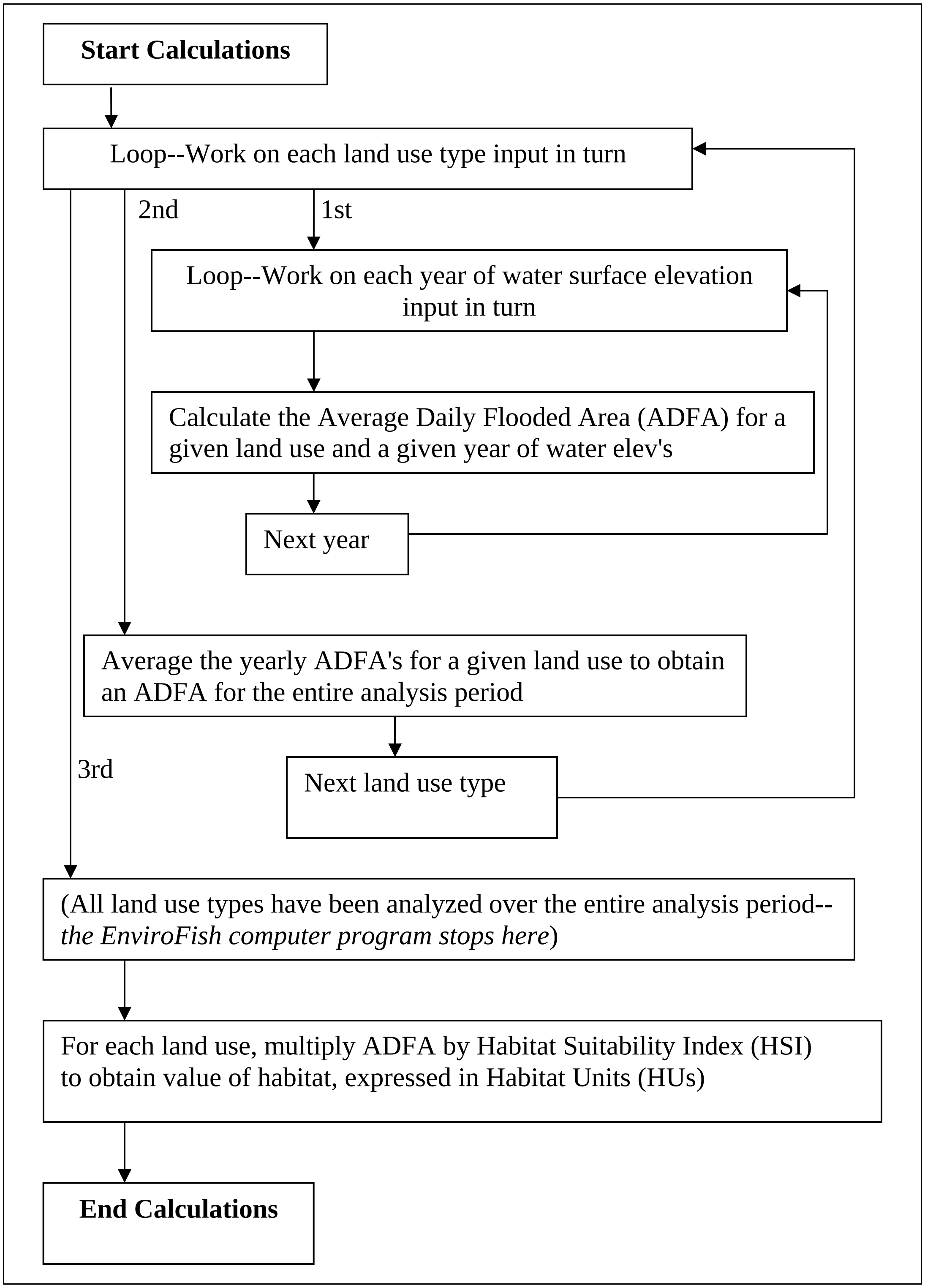


Figure 3-1. Flowchart for the Calculation of Habitat Units for Multiple Land Uses Over a Multi-Year Period of Record.

cumulative, rather than incremental. In the EnviroFish software, land area values are input for each land use category used in the analysis, rather than as a total landscape area, as discussed under the land use section below.

In the EnviroFish approach, the land described by an elevation vs. area table is treated as a single bowl-shaped depression. Figure 3-2 and Figure 3-3 illustrate how an elevation vs. area table may, or may not, realistically characterize a landscape for a spawning and rearing analysis. In both figures, a landscape subject to inundation is located alongside a levee. A culvert through the levee can evacuate surface water from connected depressions down to an elevation of 10 feet.

In Figure 3-2, there truly is one depression, although it is branched. As a water surface falls within this single bowl-shaped depression, the pooled water, shown as a blue line, is always collected into a single central body. The area of pooled water in this single depression is accurately described by an elevation vs. area table. Also, there is no isolated pool in which eggs or larvae could become stranded as the water recedes.

In Figure 3-3 there are two depressions. As in Figure 3-2, the surface water can be evacuated from the lower depression down to elevation 10 feet by the culvert. The higher, isolated depression has a bottom elevation of approximately 17 feet and a spillover elevation of 33 feet along the dividing ridge between the two depressions. The higher, isolated depression will retain water if it should become filled during flooding. Furthermore, eggs and larvae could be stranded in the isolated pool as the lower depression recedes. An elevation vs. area table for the entire landscape of Figure 3-3 would accumulate all the area in the landscape at a given elevation, even if the area were physically separated into two depressions. The scenario illustrated in Figure 3-3 is that of a water surface that has been higher than elevation 33 feet and has fallen to an elevation of approximately 26 feet in the lower depression, but a pool at elevation 33 has been stranded within the isolated depression. Due to the isolated pool, the water surface area on the landscape is actually greater than the area an elevation vs. area table would indicate for a water surface elevation of 26 feet. Alternatively, if the isolated depression contained no water and the water surface elevation in the lower depression were 26 feet, then the actual water surface area on the landscape would be less than indicated by an elevation vs. area table.

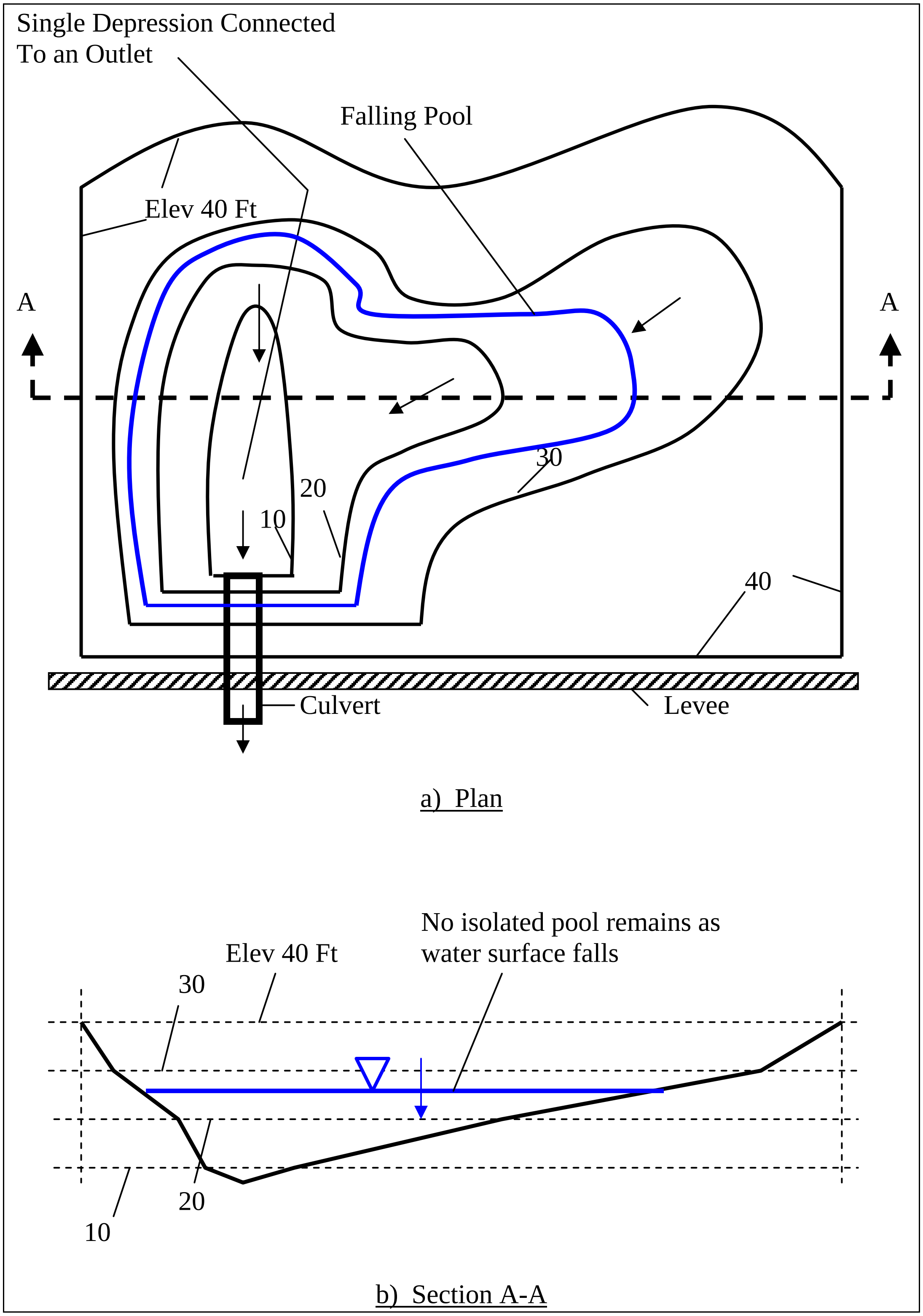


Figure 3-2. Landscape with Single Depression Connected to an Outlet.

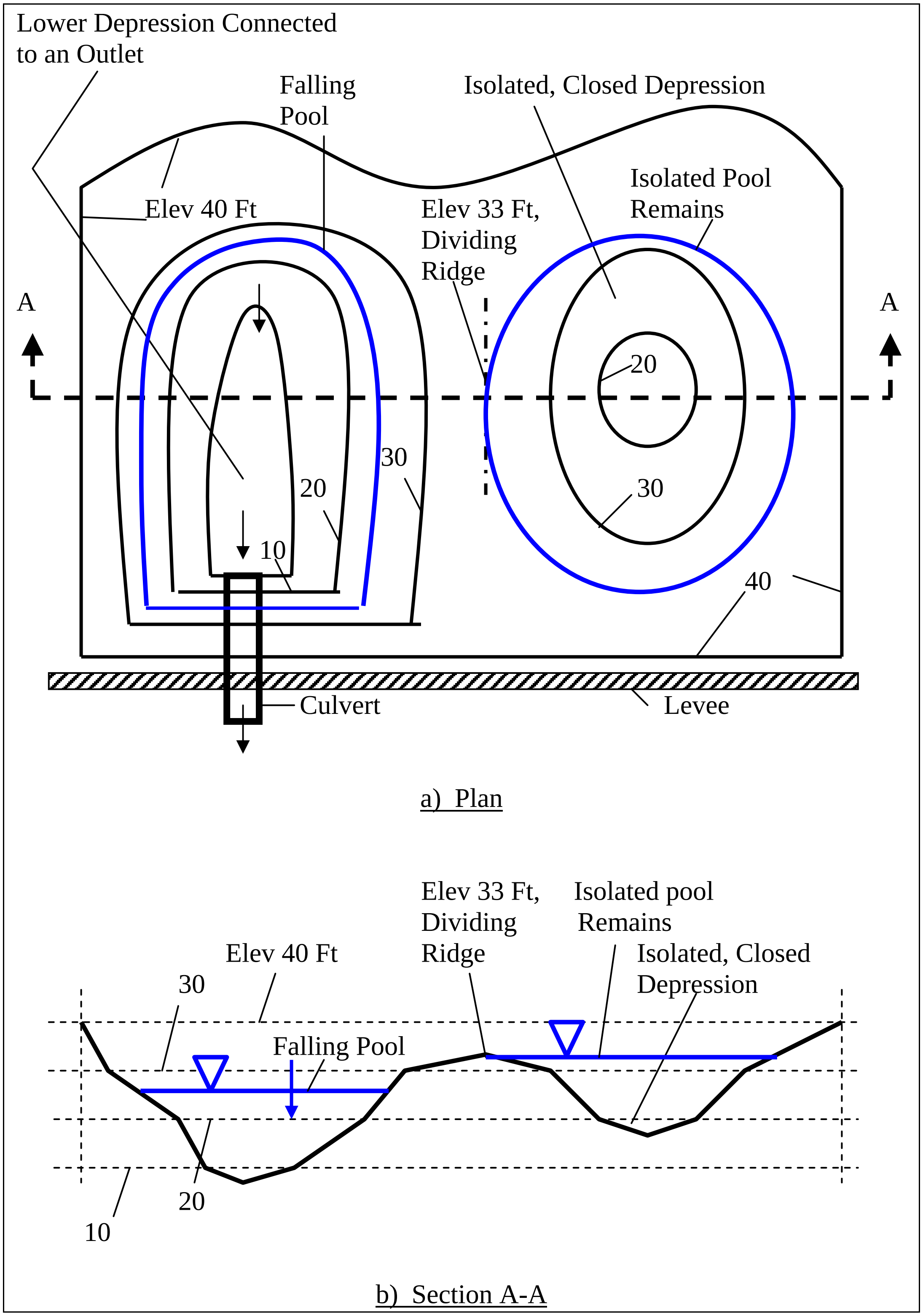


Figure 3-3. Landscape with Isolated, Closed Depression.

An isolated depression, such as the one shown in Figure 3-3, can easily exist within an actual project landscape. Careful coordination between the hydrologist, the GIS specialist, and the biologist is needed in the planning stages of an EnviroFish analysis to assure that the input reflects the topographic characteristics of the landscape with respect to the opportunities for fish to spawn and for eggs and larvae to avoid being stranded. For example, if an isolated, closed depression has ample drainage area, it may function as a permanent waterbody. If a land use classification is established for floodplain water bodies, then the isolated depression may be dealt with easily. Otherwise, the water pooled in the isolated depression may disappear during the reproductive season, due to evaporation or seepage losses, requiring continuous simulation to represent realistically. If an otherwise well-defined and isolated depression is connected by a drainage ditch to the lowest depression in the landscape, and the connection has ample flow capacity, then the water level in the isolated depression may rise and fall at essentially the same rate as that in the lowest depression. In such a case, the level pool, single depression approach of EnviroFish is realistic. However, if the connecting drainage ditch has minimal capacity, the water surface elevation in the isolated pool may considerably lag the rises and falls in the lowest depression, requiring continuous simulation to represent realistically.

Land Use

The suitability of inundated floodplains for fish during the spawning and rearing season is determined by the surface characteristics of the inundated land. These characteristics include the species and density of vegetative cover and the texture of any exposed earth. In the EnviroFish approach, land use is categorized to reflect the distribution of surface characteristics across the landscape, and boundaries of the various land uses are delineated on a map of the landscape. When combined with topographic information, elevation vs. land area tables are produced for each land use category.

For rural landscapes, land use is typically classified according to various species of crops and native trees, to stream channels, to floodplain waterbodies, and to areas of bare earth, such as loose sand. Typically the following land use categories can be delineated: agricultural, fallow, herbaceous wetlands, bottomland hardwoods, and floodplain waterbodies. The biologist classifies land use based on the selected fish species or guilds and assigns a habitat suitability index to each land use classification.

EnviroFish calculates area of each land use category referred to as Average Daily Flooded Area (ADFA).

Water Elevation

In the simplest case, the water inundating a landscape is considered to have a level surface, described by a single value of water surface elevation applicable to a 24-hour day. Daily changes in water surface elevation during the reproductive season determine how much inundated area can be successfully used for spawning and rearing. Analysis over a period of several years is necessary to ensure the variability between wet, dry, and normal years is reflected in the output. To apply the EnviroFish approach, daily water surface elevation must be entered within the spawning and rearing seasons for any year of the analysis period. For some projects, gage data may not be available to characterize existing conditions; consequently, all daily water surface elevations for existing conditions and project alternatives must be synthesized using continuous hydrologic and hydraulic simulations. If gage data are available to describe existing conditions, it may be necessary to synthesize daily water surface elevations for project alternatives that would produce significant changes in the hydrology or hydraulics of the landscape.

Spawning

In the EnviroFish approach, spawning refers to the total time necessary for deposition, fertilization, incubation, and hatching of fish eggs. For species that construct nests, additional time may be necessary prior to deposition of eggs. Some species may not actually construct nests, but scatter eggs over the substrate or attach eggs to woody debris or herbaceous vegetation. In any of these circumstances, deposited eggs are considered sessile until hatched. The term “nest” is used for all of these spawning situations. The total time for all spawning activities is referred to as the spawning period. Deposition and fertilization in a nest are considered to occur on Day 1 of the spawning period. Hatching is considered to occur on the final day of the spawning period. The spawning season is defined by the beginning and ending dates, inclusive, on which deposition and fertilization of eggs can be successfully accomplished. For the purpose of reporting, the EnviroFish approach assigns the spawning habitat available to Day 1 of the spawning period.

Figure 3-4 illustrates how spawning season and spawning period are related.

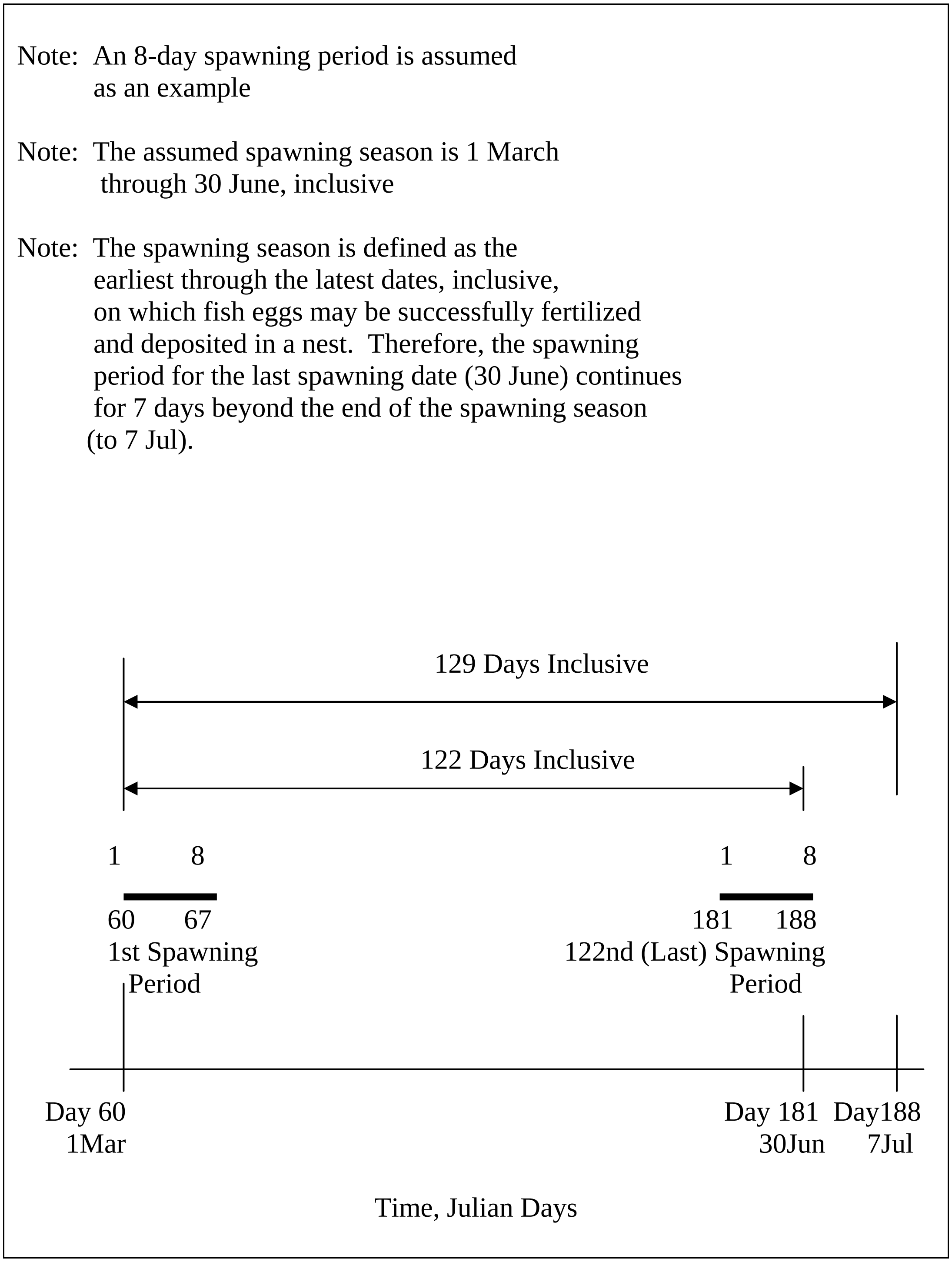


Figure 3-4. Relationship between Spawning Season and Spawning Period.

In this example, the spawning season runs from March 1 to June 30, inclusive, which is a total of 122 days. The spawning period is 8 days. A heavy horizontal bar in Figure 3-4 represents the spawning period beginning on March 1 and ending on March 8. However, each day within

the spawning season is the beginning day of a spawning period. Therefore, there are 122 spawning periods within the example spawning season. The spawning period associated with the last day of the spawning season (June 30) is also represented by a heavy horizontal bar. If the spawning that occurs on the last day of the spawning season is to be successful, suitable water depths must persist for 7 days after the ending date of the spawning season (July 7). Therefore, a total of 129 days of water surface elevation input must be analyzed. It is for this reason that the water surface elevation input to the EnviroFish program must extend for additional days past the ending date of the spawning season. The exact number of additional days required is equal to the number of days in the spawning period minus one day.

The EnviroFish approach makes use of minimum and maximum allowable spawning depths. A minimum depth of water is required for successful spawning. First, adult fish require a minimum water depth to make a nest and spawn. Secondly, after the eggs are laid in the nest, a certain depth of water cover is needed throughout the spawning period. The EnviroFish software allows the user to specify one minimum allowable spawning depth, which applies throughout the entire spawning period. If fish of the selected species or group avoid spawning at greater than a maximum limiting depth, a maximum allowable spawning depth should be applied. The EnviroFish software allows the user to specify one maximum allowable spawning depth, which applies throughout the entire spawning period.

Figure 3-5 illustrates in plan and section views a very simple bowl-shaped landscape on the first day (Day 1) of a spawning period, and the use of minimum and maximum allowable depths to locate a zone of satisfactory spawning habitat for Day 1. In section view, the water surface, shown in blue, is at elevation 100 feet. Since the example minimum allowable depth is 1 foot, the minimum allowable depth surface is at elevation 99 on Day 1. The example maximum allowable depth is 10 feet, so the maximum depth surface is at elevation 90 on Day 1. The zones satisfying depth constraints appear as green cross-hatched triangles on the left and right sides of the section. In plan view, the zone that satisfies the depth constraints on Day 1 is shaded in a green cross-hatched pattern. The fringe around the edge of the pool where the water depth ranges from 0 to 1 foot is considered unsatisfactory for spawning. Since the bottom of the bowl is deeper than elevation 90, the inundated land below elevation 90 is also considered unsatisfactory for spawning.

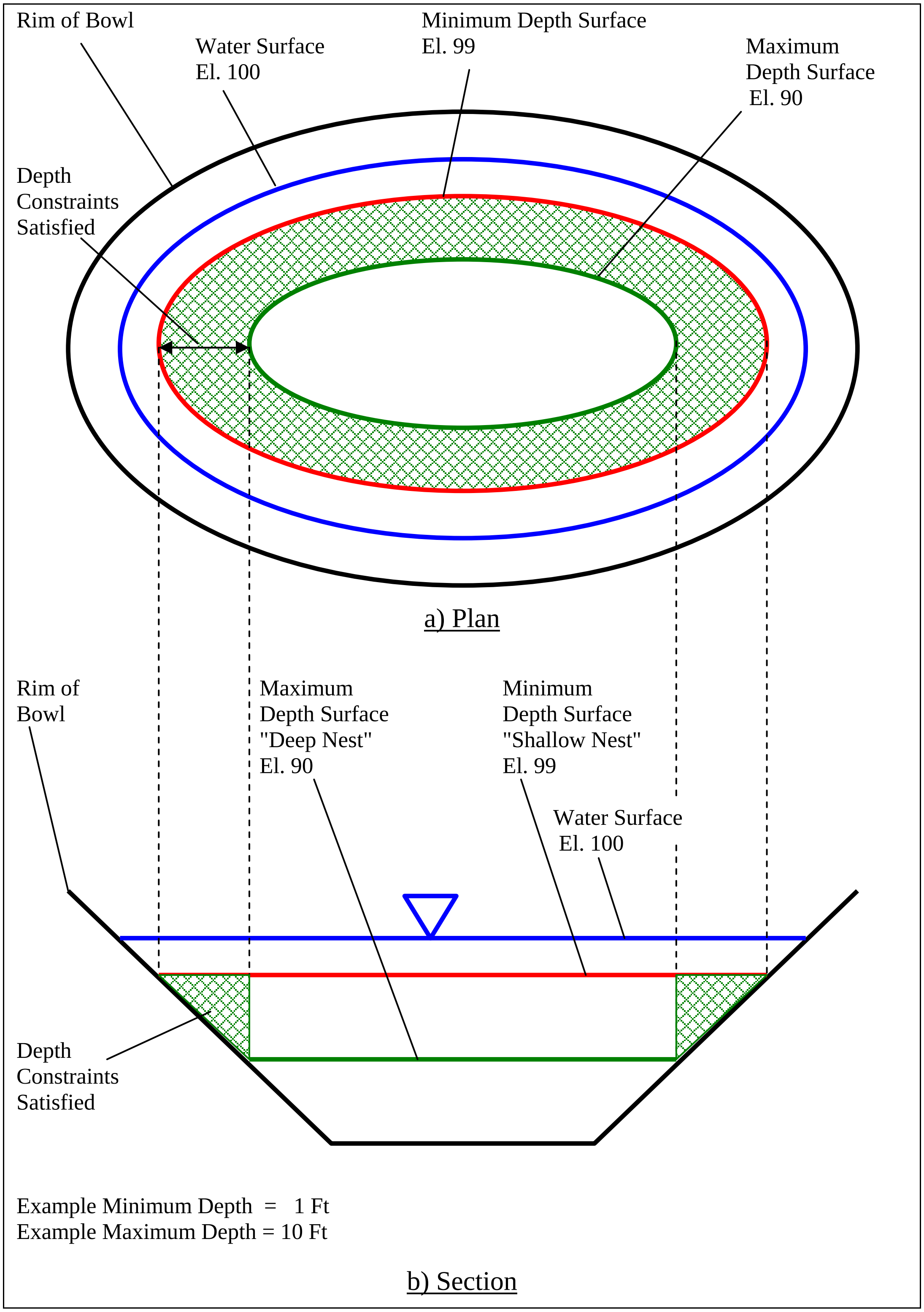


Figure 3-5. Plan and Section Views Spawning Depth Constraints within a Hypothetical Bowl of Inundated Land (Day 1).

It is important to realize that although minimum and maximum allowable depths are constant through the analysis, the water surface elevation typically varies daily. Therefore, an egg that was deposited on Day 1 within the depth range considered satisfactory on Day 1 can be subjected to unsatisfactory depths before the spawning period ends. For example, as shown in Figure 3-6, if the water level drops so much that the egg in the nest is exposed to air, then the spawning is unsuccessful. In Figure 3-6, the horizontal axis represents time and the vertical axis represents elevation. Since the egg must remain in its nest until hatching, the elevation of the deposited egg is constant throughout the spawning period. The fall in the water surface throughout the spawning period at the fixed location of the nest is represented by the blue water surface line that slopes downward to the right. The minimum and maximum allowable spawning depth lines that parallel the water surface line beyond Day 1 represent the spawning depth limits for subsequent spawning periods. On Day 1, the egg (green oval) is deposited within the satisfactory depth range. Approximately midway through the spawning period, the egg (orange oval) is still submerged, but is in water shallower than the minimum allowable depth for a subsequent spawning period. On Day 8, at the end of the spawning period, the water surface has fallen so much that the egg (red oval) is exposed to air. The egg that was deposited on Day 1 within a satisfactory depth range did not survive the spawning period.

The EnviroFish computer program has two options called "Orphaned (otherwise known as “shallow”) Nests" and "Deep Nests" that allow the user to override allowable depth restrictions. If the Orphaned Nests Allowed option is selected, the minimum allowable depth is in effect on Day 1 of a spawning period, but on the remaining days of the spawning period, depths shallower than the minimum allowable depth are considered acceptable, provided the egg is not exposed to air. Likewise, if the Deep Nests Allowed option is selected, the maximum allowable depth is in effect on Day 1 of a spawning period, but on the remaining days of the spawning period, depths greater than the maximum allowable depth are considered acceptable. Whether or not the Orphaned Nests Allowed or Deep Nests Allowed options are selected, the satisfactory depth range throughout the spawning period can never be greater than that in effect on Day 1 of the spawning period.

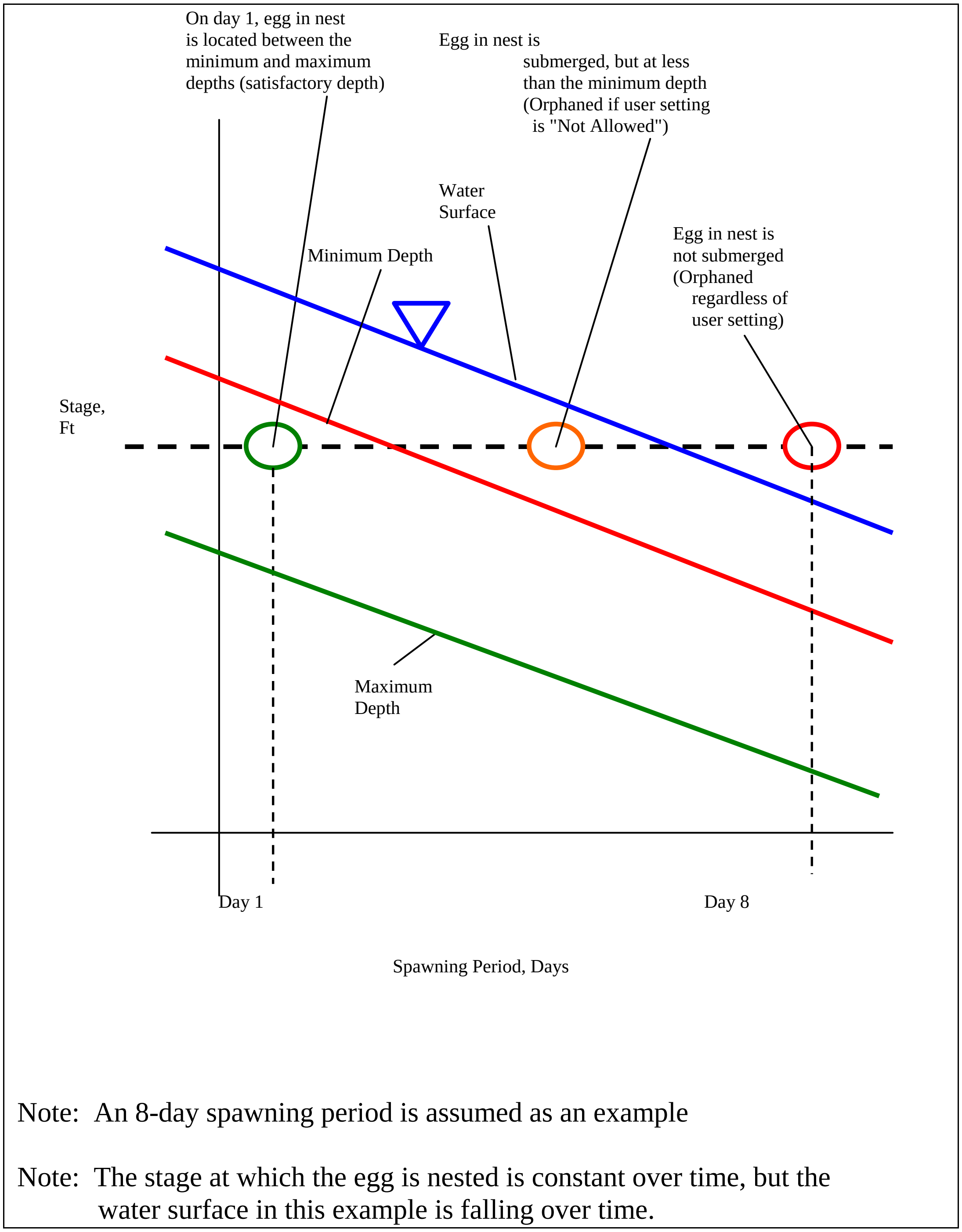


Figure 3-6. Stage Hydrograph of Spawning Constraints During Falling Stages and the Fate of an Individual Fish Egg in Its Nest.

Figure 3-7 illustrates four possible cases for selection of the Orphaned Nests and Deep Nests options for a spawning period during falling water surface elevations. For Case 1 and Case 2, the depth range that is satisfactory on Day 1, indicated by the height of the green cross-hatched area, remains in effect throughout the 8-day spawning period, even though the water is shallower

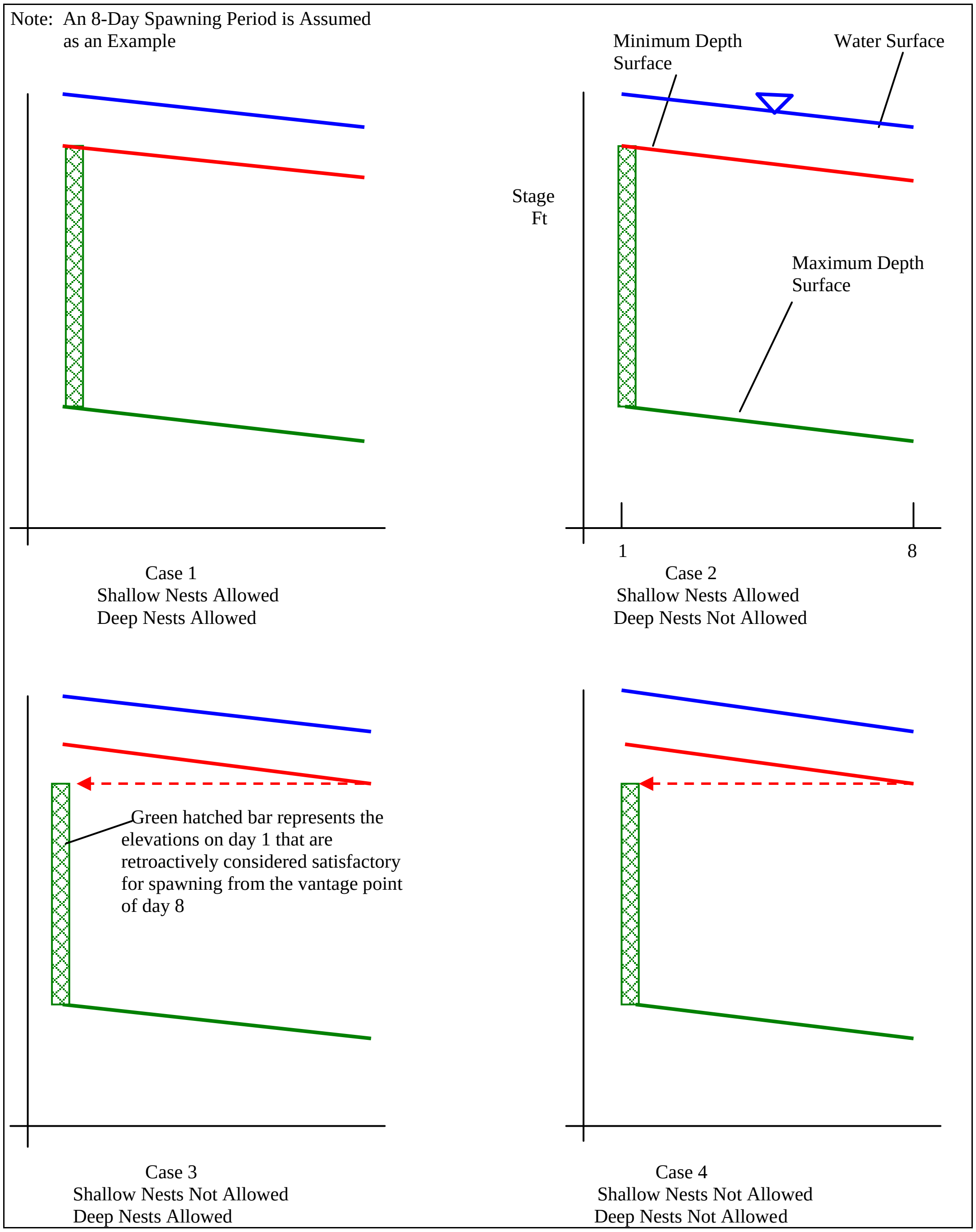


Figure 3-7. Spawning Depth Constraints for Falling Stages for the Four Possible Combinations of Shallow Nest and Deep Nest User Settings.

on Day 2 through Day 8. For Case 3 and Case 4, the depth range that is satisfactory on Day 8 is more restrictive than that for Day 1, due to the falling water surface elevation and the selection of Orphaned Nests Not Allowed. Therefore, for Case 3 and Case 4, the satisfactory depth range applicable for the entire spawning period is the reduced satisfactory depth range that has evolved by Day 8.

Figure 3-8 illustrates four possible cases for selection of the Orphaned Nests and Deep Nests options for a spawning period during rising water surface elevations. For Case 1 and Case 3, the depth range that is satisfactory on Day 1, indicated by the height of the green cross-hatched area, remains in effect throughout the 8-day spawning period, even though the water is deeper on Day 2 through Day 8. For Case 2 and Case 4, the depth range that is satisfactory on Day 8 is more restrictive than that for Day 1, due to the rising water surface elevation and the selection of Deep

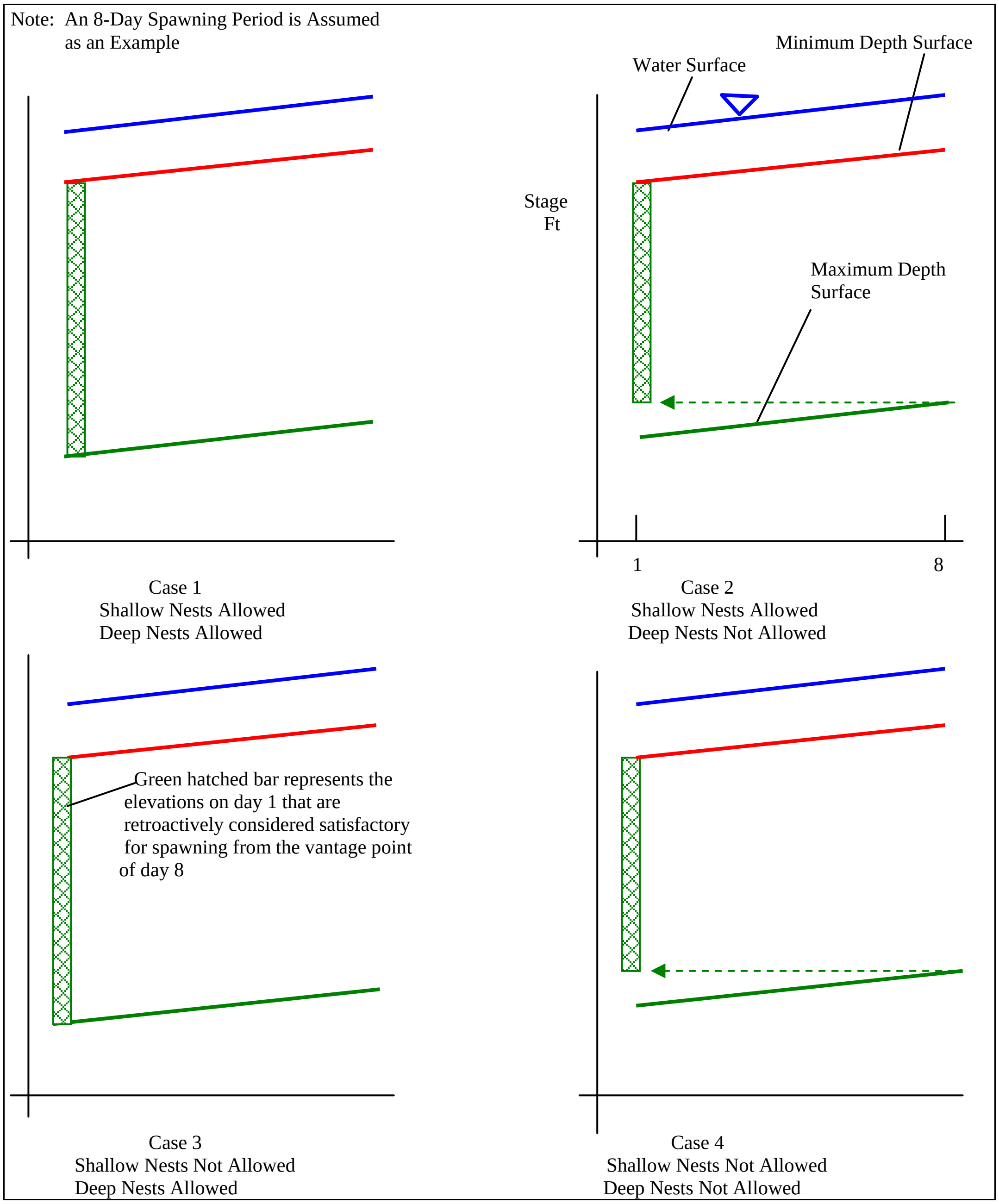


Figure 3-8. Spawning Depth Constraints for Rising Stage for the Four Possible Combinations of Shallow Nest and Deep Nest User Settings.

Nests Not Allowed. Therefore, for Case 2 and Case 4, the satisfactory depth range applicable for the entire spawning period is the reduced satisfactory depth range that has evolved by Day 8.

In the EnviroFish software, with both the Orphaned Nests Not Allowed and the Deep Nests Not Allowed options selected, it is possible for water surface elevations to change so much during a spawning period that the minimum and maximum allowable depths conflict, as shown in Figure 3-9 and Figure 3-10. In Figure 3-9, the water surface elevation is falling throughout the spawning period. The depth restriction imposed by Orphaned Nests Not

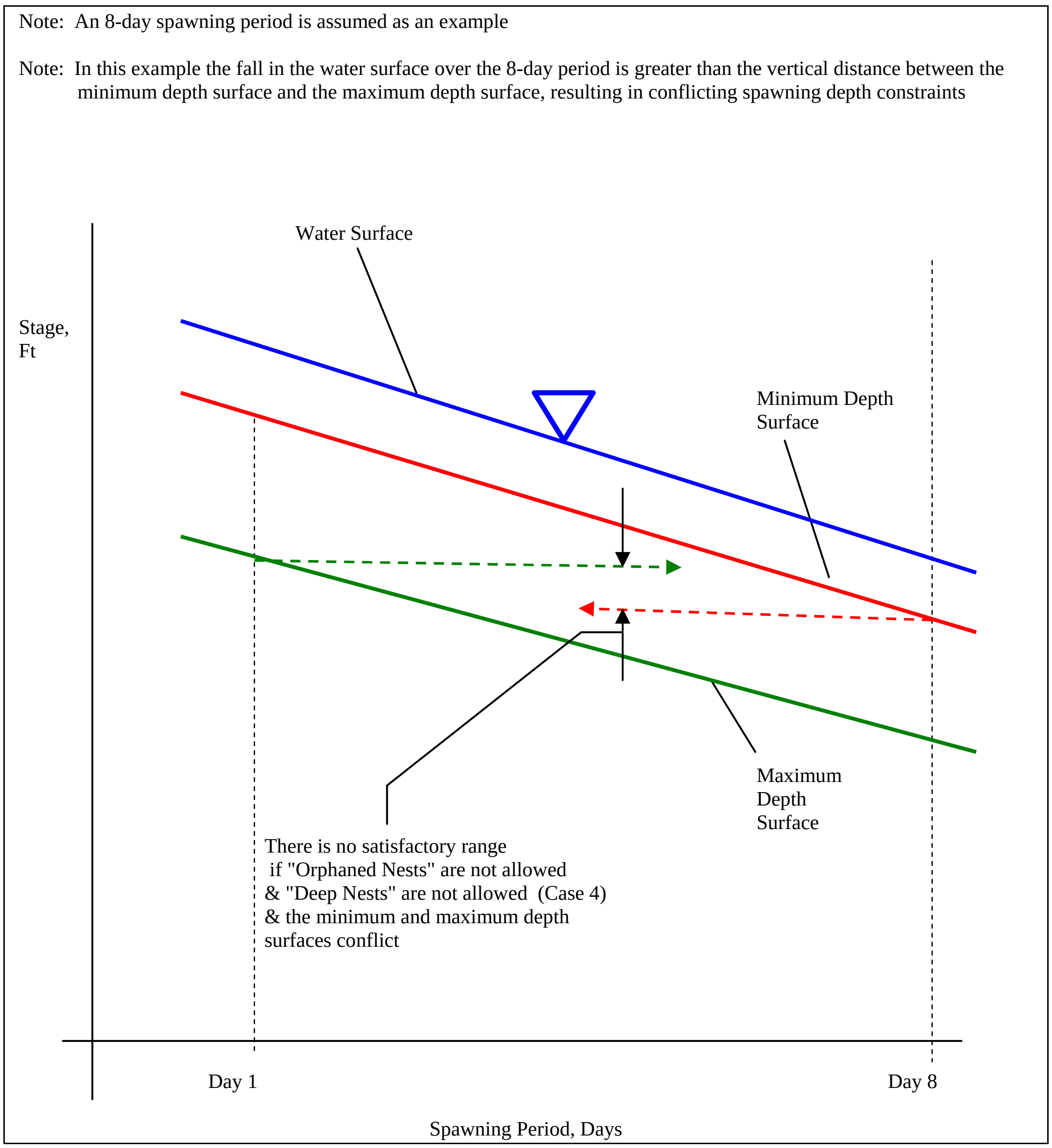


Figure 3-9. Stage Hydrograph of Spawning Constraints during Falling Stages for Case 4, with Conflicting Minimum and Maximum Depth Surfaces.

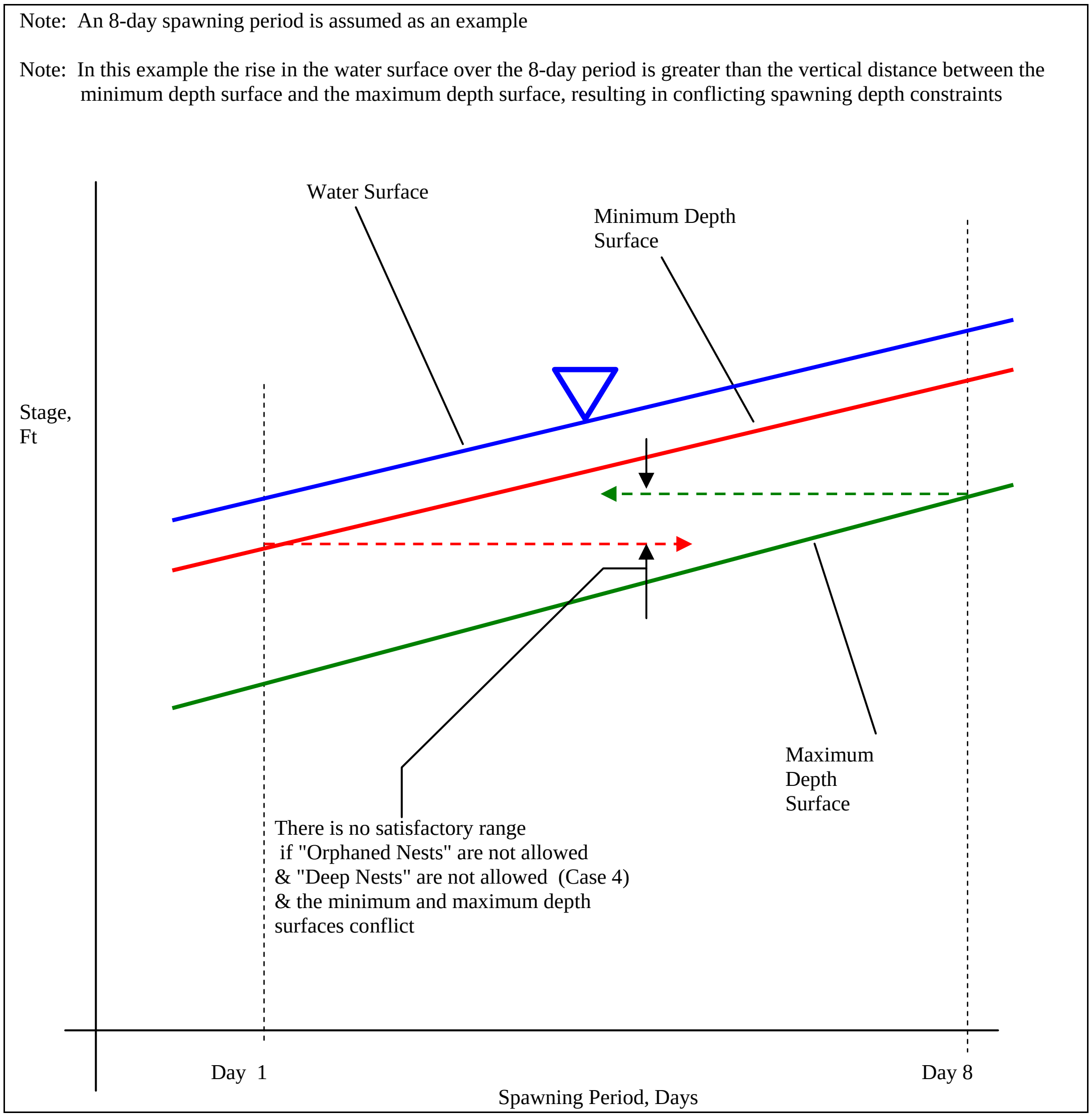


Figure 3-10. Stage Hydrograph of Spawning Constraints During Rising Stages for Case 4, with Conflicting Minimum and Maximum Depth Surfaces.

Allowed is represented by the red dashed arrow. The depth restriction imposed by Deep Nests Not Allowed is represented by the green dashed arrow. Since the deep nest restriction is associated with a higher elevation than is the Orphaned nest restriction, an unsatisfactory depth condition exists and the spawning period is considered unsuccessful. Likewise, in Figure 3-10, the water surface elevation is rising throughout the spawning period. The depth restriction imposed by Orphaned Nests Not Allowed is represented by the red dashed arrow. The depth restriction imposed by Deep Nests Not Allowed is represented by the green dashed arrow. Again, since the deep nest restriction is associated with a higher elevation than is the Orphaned nest restriction, an unsatisfactory depth condition exists and the spawning period is considered unsuccessful.

Figure 3-11 and Figure 3-12 illustrate more complex examples of changing water surface elevations throughout a spawning period, with both the Deep Nests Not Allowed and the Orphaned Nests Not Allowed options selected (Case 4). These two figures also depict the daily water surface elevations as constant during a one day time step, rather than falling or rising continuously, as is depicted in Figure 3-6 through Figure 3-10. The resultant stair-step pattern is more representative of the daily water surface elevation input to EnviroFish. Figure 3-11 depicts a fall in the

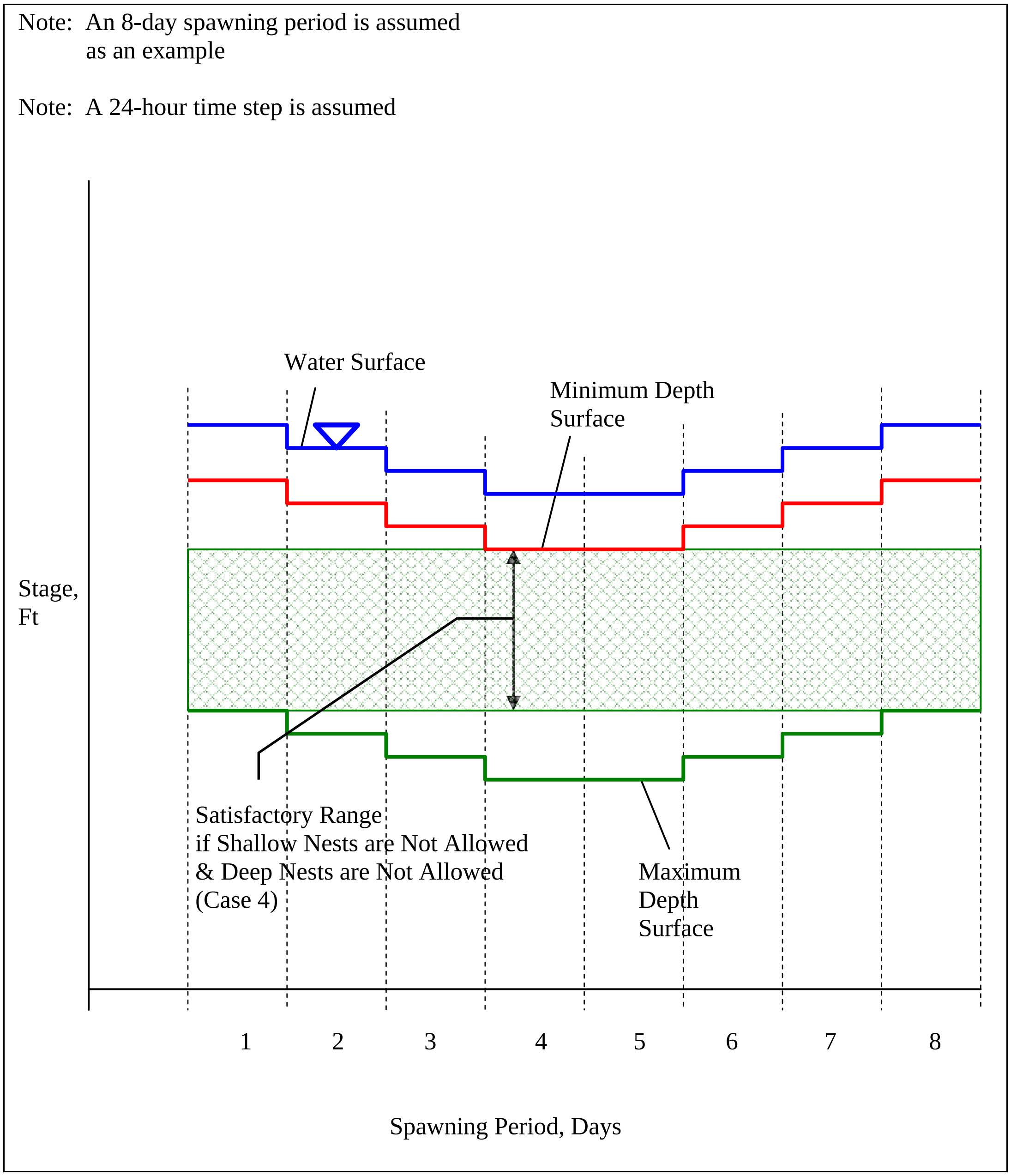


Figure 3-11. Stage Hydrograph of Spawning Constraints during Falling Stages Followed by Rising Stages for Case 4.

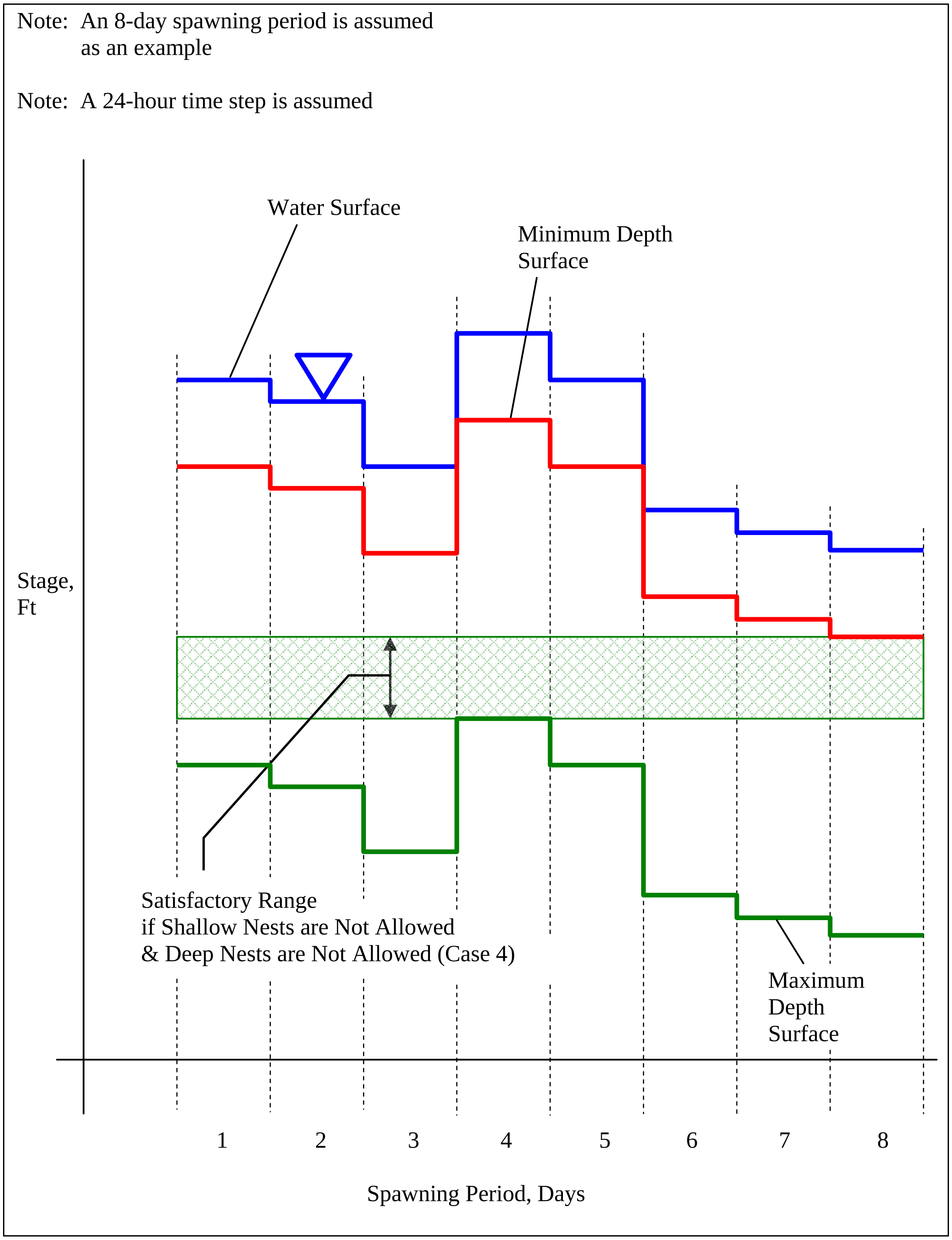


Figure 3-12. Stage Hydrograph of Spawning Constraints During Falling Stages Followed by a Rise and a Fall for Case 4.

water surface elevation, followed by a rise, during a spawning period. Since Orphaned Nests and Deep Nests are not allowed, the resultant satisfactory depth range is much smaller than the satisfactory depth range that is in effect on Day 1. Figure 3-12 depicts a fall in the water surface

elevation, followed by a rise and then another fall, during a spawning season. Again, since Orphaned Nests and Deep Nests are not allowed, the resultant satisfactory depth range is much smaller than the satisfactory depth range that is in effect on Day 1.

Rearing

In the EnviroFish approach, rearing refers to the larval life stage immediately after hatching when the individual attains the ability for volitional movement (e.g., swimming off the nest, moving with or away from the flood pulse, selecting specific habitats). If necessary, multiple larval stages can be used to characterize different developmental periods, but each stage must be run separately in EnviroFish. The rearing season coincides with the spawning period, as shown in Figure 3-13. Unlike spawning, for which each day of a multi-day spawning period must be satisfactory, each day of rearing is evaluated without respect to conditions on other days. The EnviroFish software provides two approaches to model rearing: total rearing depth and restricted rearing depth.

For the total rearing option, depths from zero to the maximum depth of the waterbody are considered satisfactory for rearing, encompassing the entire liquid volume of the waterbody. Figure 3-14 illustrates total rearing in plan and section views for a very simple bowl-shaped landscape on a given day, with zones satisfactory for rearing shaded in green cross-hatch. The EnviroFish program records the entire surface area of the waterbody as satisfactory rearing on the given date.

Compared to total rearing, the restricted depth rearing option provides a way to limit the area considered satisfactory for rearing. Restricted depth rearing treats time in the same way as total rearing and uses depth restrictions in the same way as spawning. Like total rearing, each day of restricted depth rearing is evaluated as an individual instance of a rearing opportunity, without respect to conditions on other days. Like spawning, restricted depth rearing features minimum and maximum allowable depths. For example, the minimum allowable depth may be set at 0.1 feet to prevent counting the area in a feather edge around the fringe of the waterbody where larvae could become stranded due to fluctuating water levels. A maximum allowable rearing depth may be applied if larvae avoid deep water (e.g., to minimize predation) or otherwise do not derive benefits at greater depths.

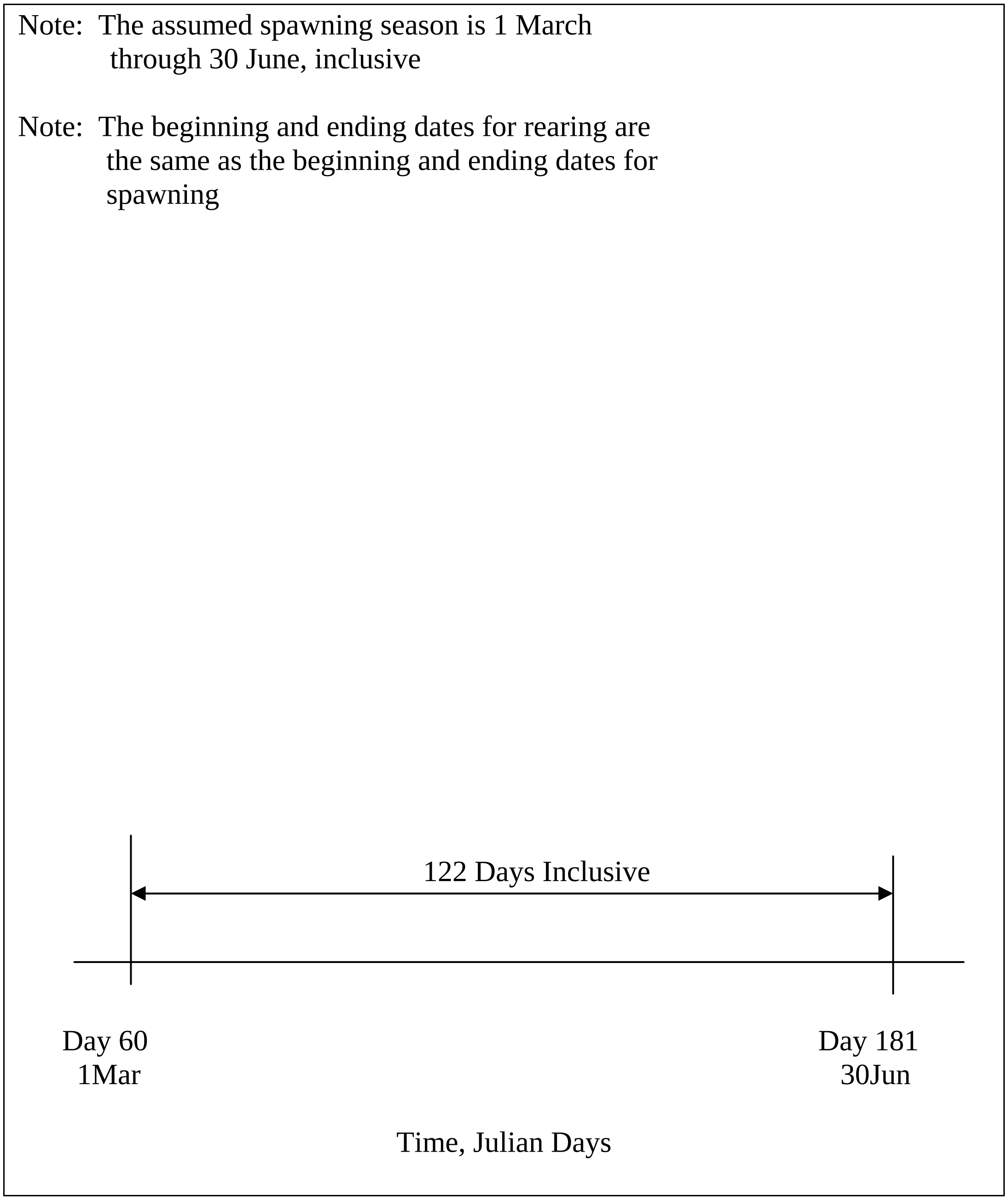


Figure 3-13. Timeline of Rearing Period.

Figure 3-15 illustrates in plan and section views a very simple bowl-shaped landscape, and the use of minimum and maximum allowable depths to locate a zone of satisfactory restricted depth rearing. In section view, the water surface, shown in blue, is at elevation 100 feet. Since the example minimum allowable depth is 0.1 foot, the minimum allowable depth surface is at elevation 99.9. The example maximum allowable depth is 10 feet, so the maximum depth surface is at elevation 90. The zones satisfying depth constraints appear as green cross-hatched triangles on the left and

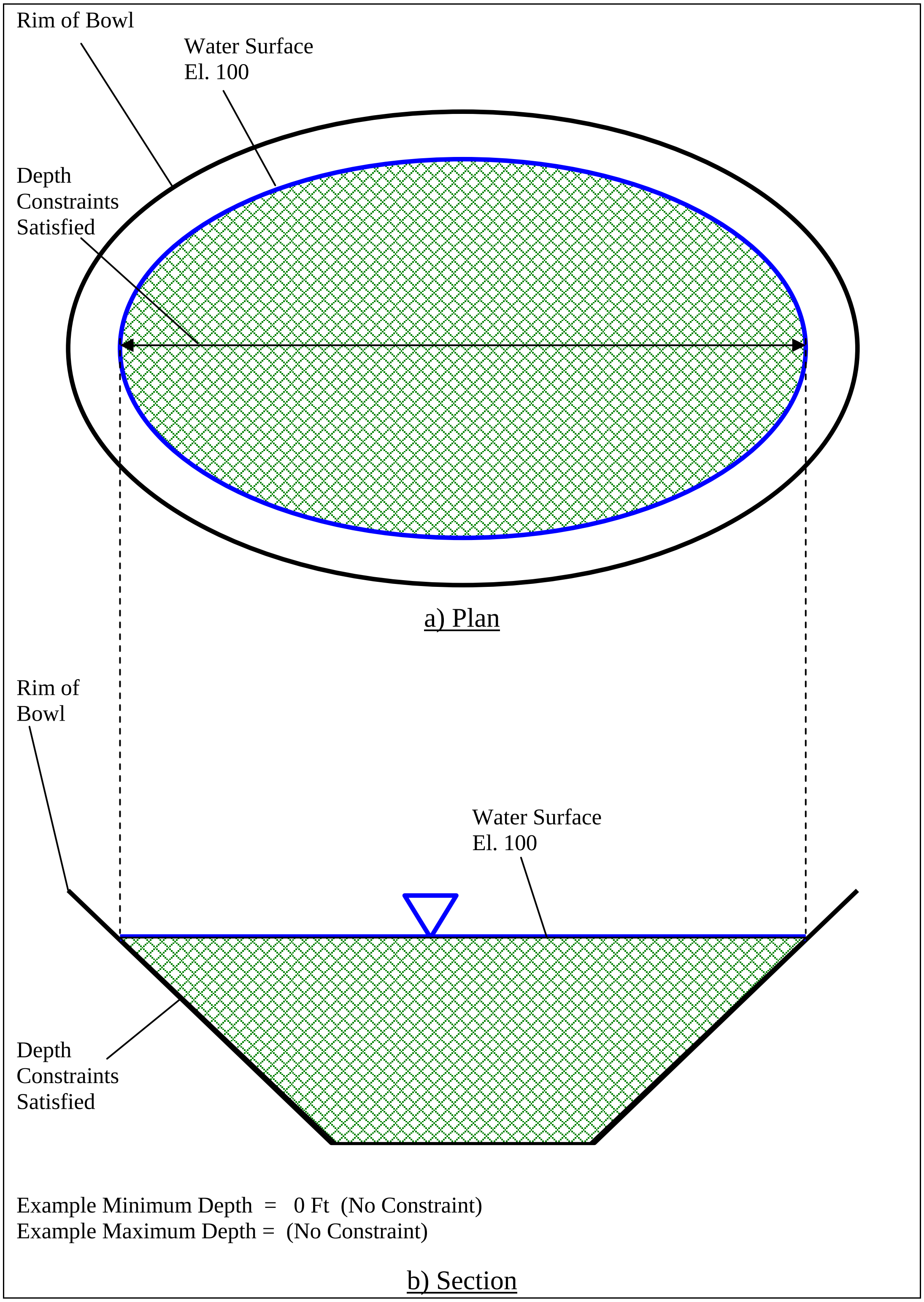


Figure 3-14. Plan and Section Views of Total Rearing Depth Constraints within a Hypothetical Bowl of Inundated Land.

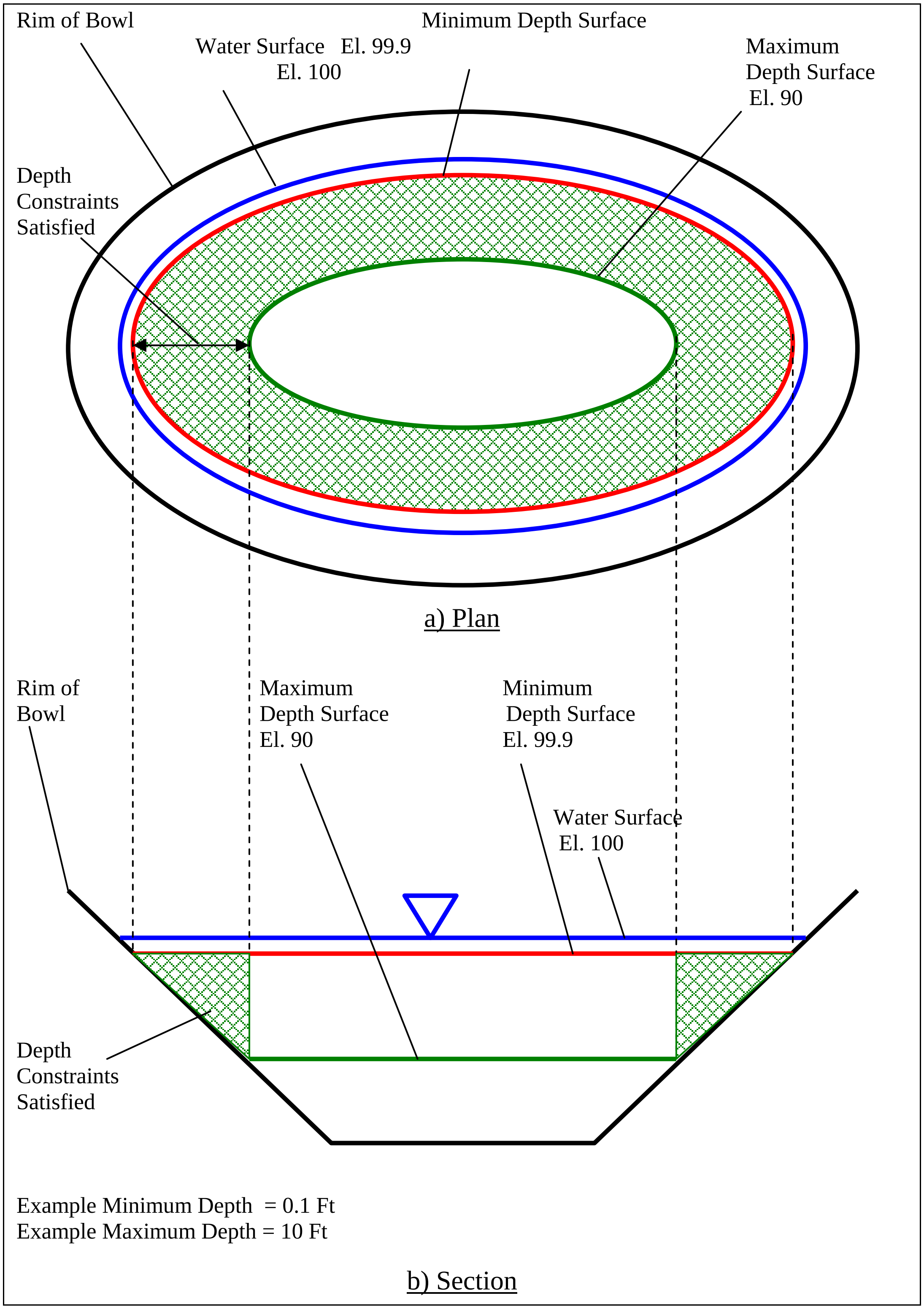


Figure 3-15. Plan and Section Views of Restricted Rearing Depth Constraints within a Hypothetical Bowl of Inundated Land.

right sides of the section. In plan view, the zone that satisfies the depth constraints is shaded in a green cross-hatched pattern. The fringe around the edge of the pool where the water depth ranges from 0.0 to 0.1 foot is considered unsatisfactory for rearing. Since the bottom of the bowl is deeper than elevation 90, the inundated land below elevation 90 is also considered unsatisfactory for rearing.

4 Running EnviroFish

This chapter describes running the EnviroFish program, including loading input, initiating a program run, and obtaining output. The example input and output is in the example problem of Chapter 6. The content of this chapter is organized under eight headings—operating system, input required, navigation, input steps, input description, initiating a program run, viewing output, and output description. A detailed description of EnviroFish calculations is shown in Appendix C.

Operating System

The EnviroFish computer program runs under the Microsoft Windows computer operating system. Figure 4-1 is a screen shot of the EnviroFish main page upon program startup. The page is blank, because no DSS file has been loaded and no habitat constraints have been entered.

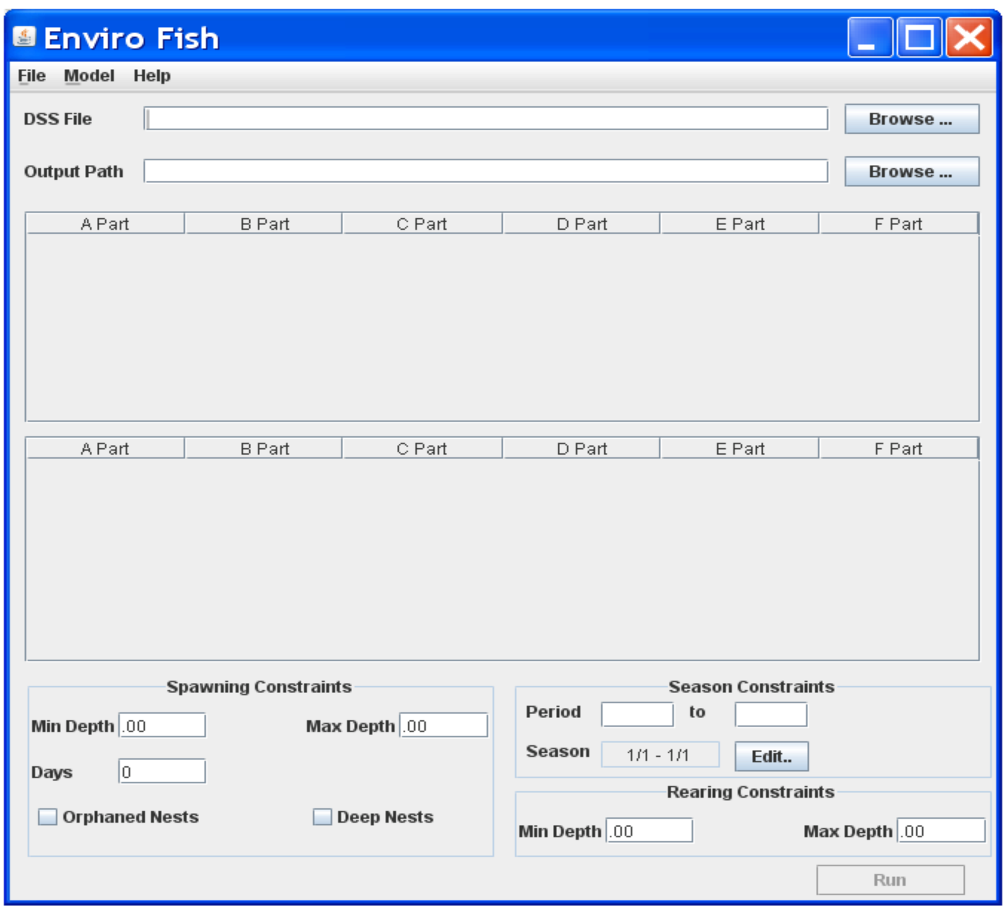


Figure 4-1. EnviroFish Main Screen on Start-up.

Input Required

The input requirements for EnviroFish are simple, although the preparation of that input may be complex. The first body of input required is daily water surface elevations throughout the analysis period for the landscape being analyzed, referred to as "daily elevations" below. Typically, different alternatives have different water surface elevation input for the same analysis period. The second body of input is a set of elevation vs. area tables, with one table for each category of land use in the landscape. Both the daily elevations and the elevation vs. area tables must be stored in the DSS file format established by the Corps of Engineers Hydrologic Engineering Center. EnviroFish loads only one DSS file for a program run, so the elevation data and the elevation vs. area data must both be stored in one DSS file. Therefore, a program run is required for each combination of elevation (e.g., Alternatives) and elevation-area (e.g., each land use category) data. See Appendix B for more information about using DSS files to incorporate land use in EnviroFish.

Figure 4-2 is a screen shot of the EnviroFish main page with an example DSS file named **Any River Basin.dss** loaded. The DSS pathname containing the elevation data to be used is highlighted in the upper DSS window, and the pathname containing the elevation-area data to be used is highlighted in the lower DSS window. Different combinations of elevation and elevation vs. area may be selected.

In addition to the input provided in DSS format, habitat constraints regarding time and depth must be entered for spawning and rearing. The constraints are entered from the keyboard directly into the EnviroFish main window.

Navigation

Navigating the EnviroFish view screens may be performed by placing the cursor of the mouse over the desired area to be selected and pressing the left button of the mouse. The Tab key on the computer keypad may be used to accept input data and move from one area to another. The Arrow keys on the computer keypad may be used to navigate to a particular area; the Enter key may be used to accept data.

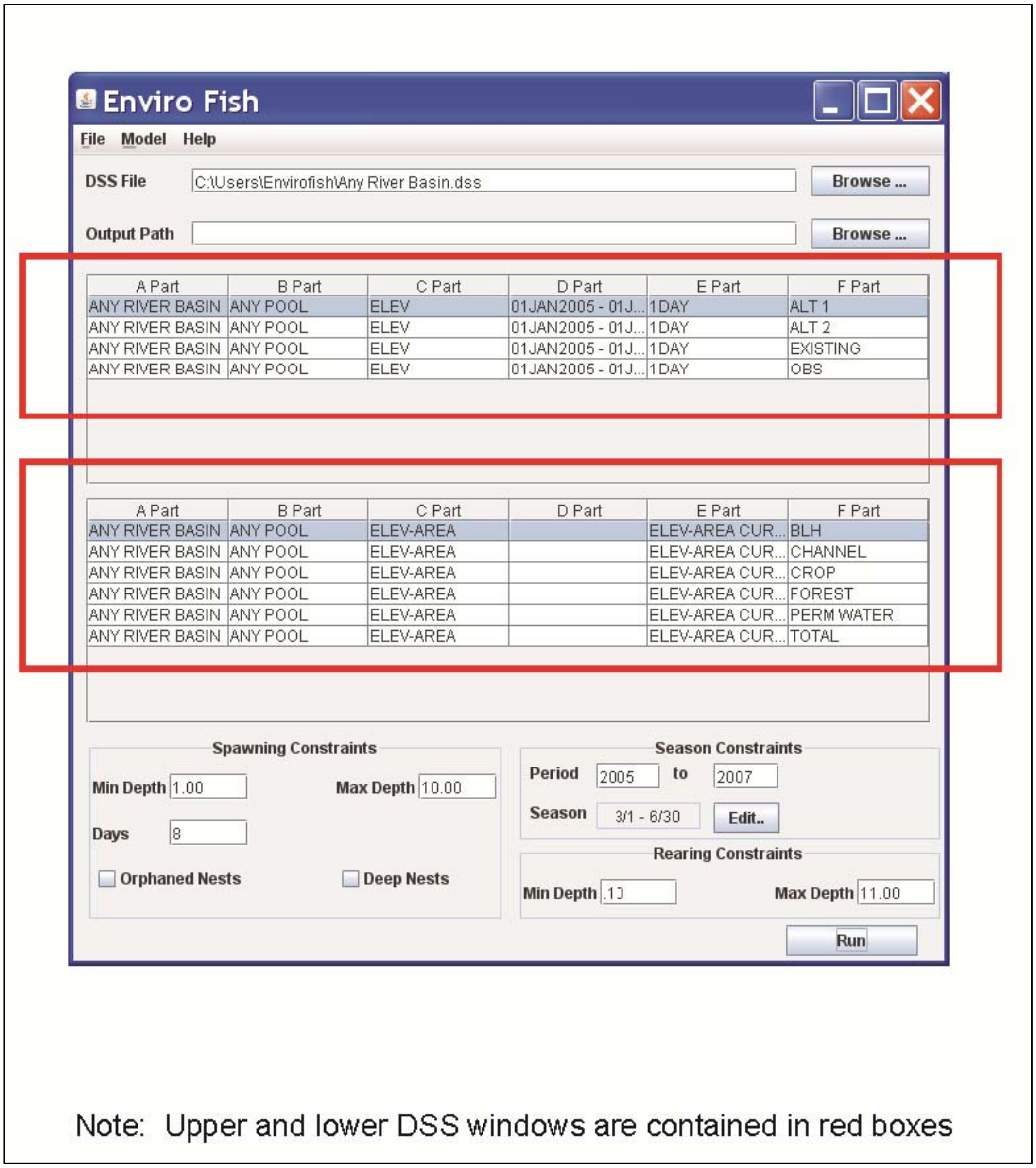


Figure 4-2. EnviroFish Main Screen, Upper and Lower DSS Windows.

Input Steps

From the EnviroFish main screen, shown in Figure 4-1, the following four input steps are required (data may be entered or loaded in any order):

1. Open the DSS file containing the elevation and elevation-area data, either using the **Browse** button in the upper right corner of the EnviroFish main screen or by selecting **Open** from the **File** pull down menu in the upper left corner of the EnviroFish main screen. Click to select the desired elevation vs. area path.

(Note that DSS file C Part pathnames must be identical to those found under the **Preferences** tab from the **File** pull down menu. The default C Part pathnames are **ELEV** and **ELEV-AREA** for the elevation and elevation-area data, respectively. If the DSS file contains different C Part pathnames, the **Preferences** tab can be used to change the C Part pathnames to match the DSS file C Part pathnames, or HEC-DSSvue must be used to change the DSS file C Part pathnames to match the default EnviroFish C Part pathnames. Pathname parts associated with elevation data will appear in the upper DSS EnviroFish window and those associated with elevation-area data will appear in the lower DSS EnviroFish window on the EnviroFish main screen when data has been successfully retrieved. See Figure 4-2.)

2. Set the habitat constraints on the EnviroFish main screen. See Figure 4-3 for the location of habitat constraint windows on the EnviroFish main screen. A description of the EnviroFish habitat constraint variables is provided below in the Input Description section.
3. From the **Model** pull down menu in the upper left corner of the EnviroFish main screen, select **Calc Summary** and/or **Calc Daily**. **Calc Summary** (*.evf file), which lists seasonal and analysis period summaries, and **Calc Daily** (*.txt file), which lists daily results for the entire analysis period, can be saved in *.txt, *.csv, and *.xls (Excel) formats.
4. An output path can be specified from the **Browse** button, located opposite from **Output Path** on the EnviroFish main screen. Upon execution of the EnviroFish program, the *.evf file generated from the **Calc Summary** option is copied to the specified output path.

Input Description

The defined and described terms highlighted in bold below appear on the main screen of EnviroFish as guides for entering input and setting constraints.

Rearing. The larval stage in the life-cycle of a fish from hatching to juvenile.

Rearing Constraints. The minimum and maximum depths for restricted rearing.

Max Depth, i.e. Maximum Depth. The vertical distance below the water surface that establishes the lower boundary for each day.

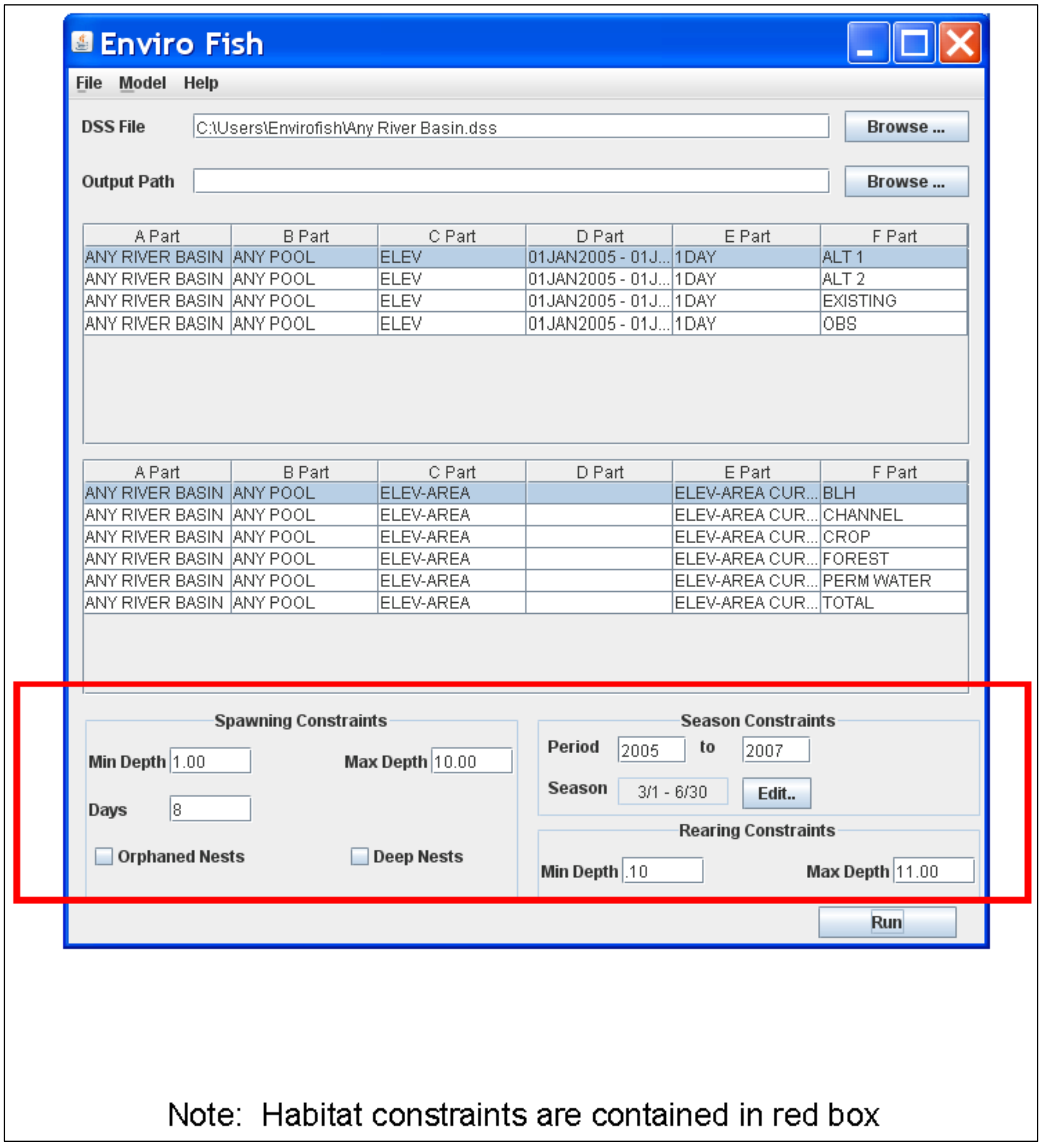


Figure 4-3. EnviroFish Main Screen, Habitat Constraints.

Min Depth, i.e. Minimum Depth. The vertical distance below the water surface that establishes the upper boundary for each day.

Season Constraints. Calculation limits for spawning.

Period. The beginning and ending years for spawning calculations.

Season. The beginning and ending calendar dates for spawning calculations for the period selected. Note that a spawning constraint duration that is greater than one day will include information that extends beyond the ending calendar date.

Spawning. The stage in the life-cycle of a fish that includes nest construction, egg deposition, incubation, and hatching.

Spawning Constraints. Time and depth requirements for spawning.

Days. Spawning duration in days.

Deep Nests. If this box is checked, it indicates that eggs deposited near the maximum spawning depth on Day 1 survive during a rising river stage. An unchecked box is the default setting, indicating that any departure from the allowable user-defined depth and duration criteria will not be counted.

Max Depth, i.e. Maximum Depth. The maximum vertical distance below the water surface that a fish can or will deposit eggs.

Min Depth, i.e. Minimum Depth. The minimum vertical distance below the water surface that a fish can or will deposit eggs.

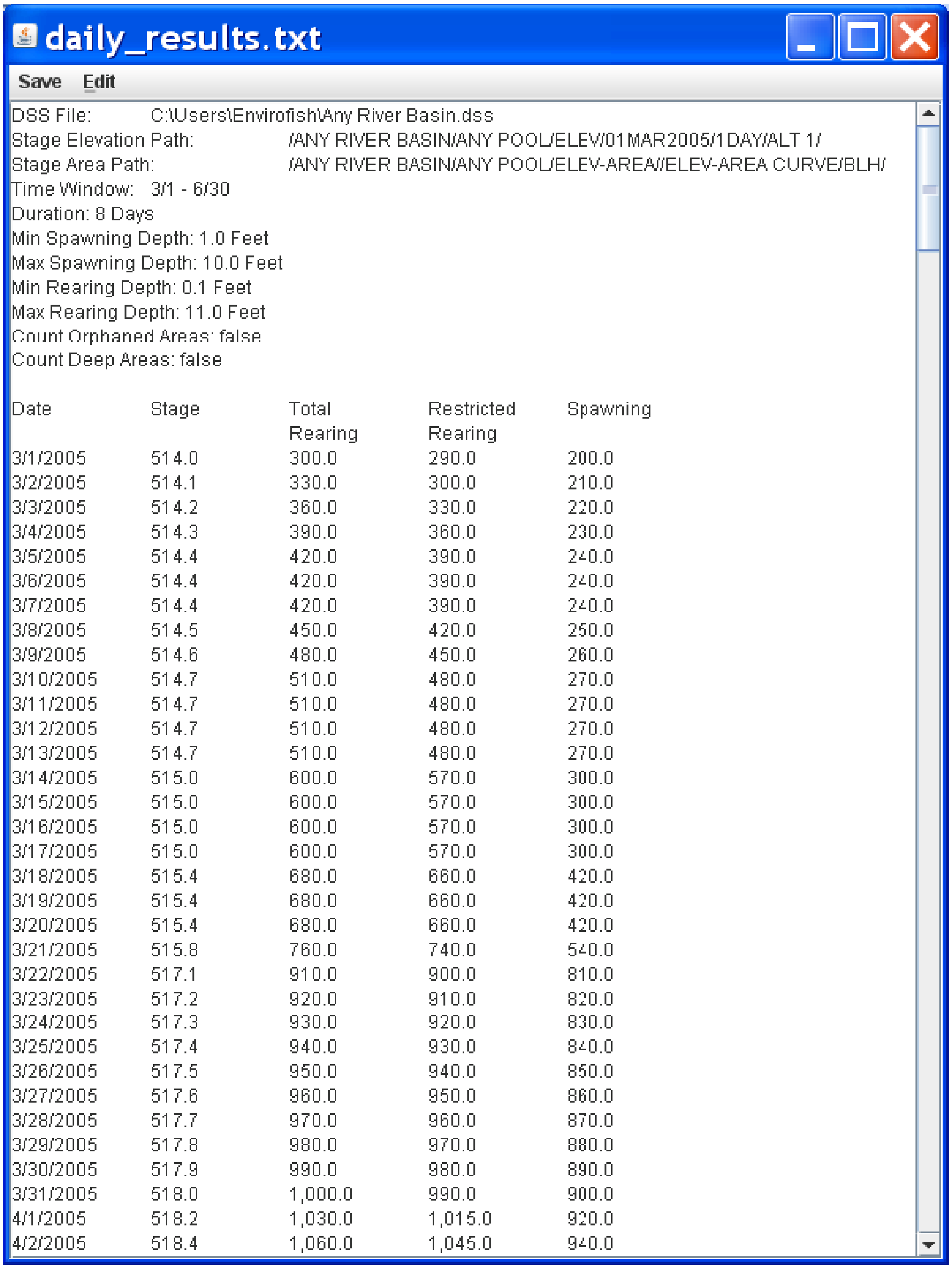
Orphaned Nests. If this box is checked, it indicates that eggs deposited near the minimum spawning depth on Day 1 survive during a falling river stage until exposed to air. An unchecked box is the default setting, indicating that any departure from the allowable user-defined depth and duration criteria will not be counted.

Initiating a Program Run

To initiate a program run, after completing the input steps, place the cursor of the mouse over the **Run** button located in the lower right corner of the EnviroFish main screen (see Figure 4-2) and press the left button on the mouse. The EnviroFish computer program will execute and the output file type(s) selected will be available for viewing on the computer Desktop.

Viewing Output

EnviroFish is capable of producing two output files—a daily results file and a summary file. Each output represents a single EnviroFish run of elevation and elevation-area data. Screen shots of example daily results and summary files are provided in Figure 4-4 and Figure 4-5, respectively. The output shown in the two figures is based on the input selections shown in Figure 4-2.


daily_results.txt

Save Edit

DSS File: C:\Users\Envirofish\Any River Basin.dss
Stage Elevation Path: /ANY RIVER BASIN/ANY POOL/ELEV/01MAR2005/1DAY/ALT 1/
Stage Area Path: /ANY RIVER BASIN/ANY POOL/ELEV-AREA//ELEV-AREA CURVE/BLH/
Time Window: 3/1 - 6/30
Duration: 8 Days
Min Spawning Depth: 1.0 Feet
Max Spawning Depth: 10.0 Feet
Min Rearing Depth: 0.1 Feet
Max Rearing Depth: 11.0 Feet
Count Orphaned Areas: false
Count Deep Areas: false

Date	Stage	Total Rearing	Restricted Rearing	Spawning
3/1/2005	514.0	300.0	290.0	200.0
3/2/2005	514.1	330.0	300.0	210.0
3/3/2005	514.2	360.0	330.0	220.0
3/4/2005	514.3	390.0	360.0	230.0
3/5/2005	514.4	420.0	390.0	240.0
3/6/2005	514.4	420.0	390.0	240.0
3/7/2005	514.4	420.0	390.0	240.0
3/8/2005	514.5	450.0	420.0	250.0
3/9/2005	514.6	480.0	450.0	260.0
3/10/2005	514.7	510.0	480.0	270.0
3/11/2005	514.7	510.0	480.0	270.0
3/12/2005	514.7	510.0	480.0	270.0
3/13/2005	514.7	510.0	480.0	270.0
3/14/2005	515.0	600.0	570.0	300.0
3/15/2005	515.0	600.0	570.0	300.0
3/16/2005	515.0	600.0	570.0	300.0
3/17/2005	515.0	600.0	570.0	300.0
3/18/2005	515.4	680.0	660.0	420.0
3/19/2005	515.4	680.0	660.0	420.0
3/20/2005	515.4	680.0	660.0	420.0
3/21/2005	515.8	760.0	740.0	540.0
3/22/2005	517.1	910.0	900.0	810.0
3/23/2005	517.2	920.0	910.0	820.0
3/24/2005	517.3	930.0	920.0	830.0
3/25/2005	517.4	940.0	930.0	840.0
3/26/2005	517.5	950.0	940.0	850.0
3/27/2005	517.6	960.0	950.0	860.0
3/28/2005	517.7	970.0	960.0	870.0
3/29/2005	517.8	980.0	970.0	880.0
3/30/2005	517.9	990.0	980.0	890.0
3/31/2005	518.0	1,000.0	990.0	900.0
4/1/2005	518.2	1,030.0	1,015.0	920.0
4/2/2005	518.4	1,060.0	1,045.0	940.0

Figure 4-4. EnviroFish Daily Results Example.

Both the daily and summary output files can be saved in *.txt, *.csv, and *.xls (Excel) formats. After an EnviroFish output file has been opened, place the cursor over the **Save** pull down menu in the upper left corner and press the left button on the mouse. Using a similar process, select the file type, select the output path location by using the browser, type in the desired filename, and finally select the **Save** button in the lower right corner of the window box.

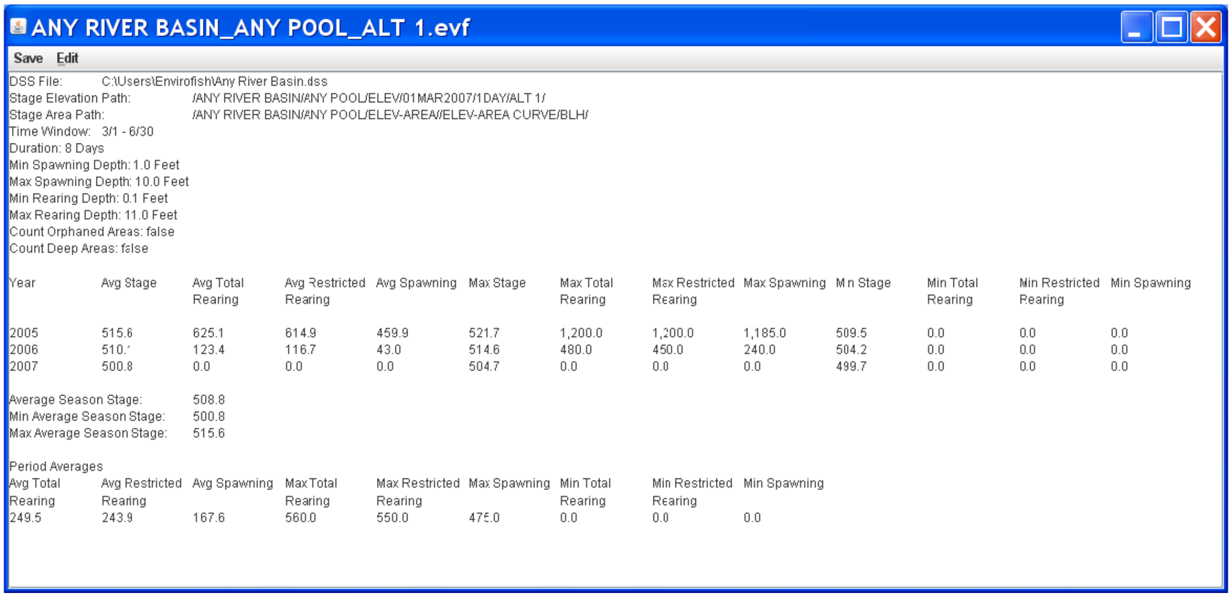


Figure 4-5. EnviroFish Summary Results Example.

Output Description

The defined and described terms highlighted in bold below appear in the EnviroFish daily and summary output files. Daily results are listed first. Summary results are listed second.

1. Daily results--this output file lists daily results for the entire analysis period:

   Date. The month/day/year corresponding to each day's results.

   Restricted Rearing. The amount of land area confined by the minimum and maximum rearing depths.

   Spawning. The amount of land area limited by the minimum and maximum spawning depths, spawning duration, and orphaned and deep nest selections.

   Stage. The daily stage (referred to as elevation in this *User'sManual*) utilized for spawning and rearing calculations usually associated with an alternative.

   Stage Area Curves. A tabulation of the stage area curve (referred to as elevation-area data in this *User's Manual*) utilized in rearing and spawning calculations obtained from the DSS stage area file. The area 1

column consists of the land use (e.g., bottomland hardwoods) area input values, each of which defines the total amount of area at and below a corresponding stage or elevation. The stage column consists of the stage or elevation input values that correspond to the land use area input values.

Total Rearing. The amount of land area below the water surface.

2. Summary results--this file summarizes results for the entire analysis period; descriptions below are divided into (A) a seasonal sub-list and (B) an analysis period sub-list:

    a. Output that provides summary data for each season (year) independently.

    Avg Restricted Rearing, i.e., Average Restricted Rearing. Arithmetic mean daily restricted rearing value.

    Avg Spawning, i.e., Average Spawning. Arithmetic mean daily spawning value.

    Avg Stage, i.e., Average stage. Arithmetic mean daily stage.

    Avg Total Rearing, i.e., Average Total Rearing. Arithmetic mean daily total rearing value.

    Min Restricted Rearing, i.e., Minimum Restricted Rearing. Lowest daily restricted rearing value.

    Min Spawning, i.e., Minimum Spawning. Lowest daily spawning value.

    Min Stage, i.e., Minimum Stage. Lowest daily stage.

    Min Total Rearing, i.e., Minimum Total Rearing. Lowest daily total rearing value.

    Max Restricted Rearing, i.e., Maximum Restricted Rearing. Highest daily restricted rearing value.

Max Spawning, i.e., Maximum Spawning. Highest daily spawning value.

Max Stage, i.e., Maximum Stage. Highest daily stage.

Max Total Rearing, i.e., Maximum Total Rearing. Highest daily total rearing value.

Year. The year corresponding to each season's results.

b. Overall Summary Results. Output that provides summary data for the entire analysis period.

Average Season Stage. Arithmetic mean daily stage.

Avg Restricted Rearing, i.e., Average Restricted Rearing. Arithmetic mean daily restricted rearing value.

Avg Spawning, i.e., Average Spawning. Arithmetic mean daily spawning value.

Avg Total Rearing, i.e., Average Total Rearing. Arithmetic mean daily total rearing value.

Max Average Season Stage, i.e., Maximum Average Season Stage. Highest average season stage value.

Max Restricted Rearing, i.e., Maximum Restricted Rearing. Arithmetic mean of the highest daily restricted rearing values in each season.

Max Spawning, i.e., Maximum Spawning. Arithmetic mean of the highest daily spawning values in each season.

Max Total Rearing, i.e., Maximum Total Rearing. Arithmetic mean of the highest daily total rearing values in each season.

Min Average Season Stage, i.e., Minimum Average Season Stage. Lowest average season stage value.

Min Restricted Rearing, i.e., Minimum Restricted Rearing. Arithmetic mean of the lowest daily restricted rearing values in each season.

Min Spawning, i.e., Minimum Spawning. Arithmetic mean of the lowest daily spawning values in each season.

Min Total Rearing, i.e., Minimum Total Rearing. Arithmetic mean of the lowest daily total rearing values in each season.

5 Application Considerations

This chapter addresses five considerations that are likely to arise in applying the EnviroFish approach to typical projects: multiple spawning seasons, project alternatives, mitigation, water surface elevation input, and pools and flowlines.

Multiple Spawning Seasons

Although the discussion and the example problem in this *User's Manual* are limited to consideration of a single spawning season, the EnviroFish approach can be used to analyze multiple spawning seasons. To analyze multiple spawning seasons with the EnviroFish software, the spawning seasons are analyzed in separate program runs.

Project Alternatives

If enough data are available, or may be synthesized, the EnviroFish approach can be applied to a wide range of project alternatives, including existing conditions, future without project conditions, particular project alternatives, and pristine conditions.

Mitigation

If project impacts are to be mitigated within the project landscape, the EnviroFish approach may be applied to the mitigation area itself, to evaluate the value of the mitigation as affected by project-induced changes in hydrology and hydraulics.

Water surface elevation input

The EnviroFish approach uses one water surface elevation value to characterize inundation over a 24 hour period for the landscape being analyzed. Missing water surface elevation data within the spawning season is not permitted in an EnviroFish analysis. Typically, available raw gage data has missing data and is not suitable as direct input into EnviroFish. Moreover, the use of EnviroFish for analyzing project alternatives may require the synthesis of water surface elevation input. Issues related to the development of water surface elevation input for EnviroFish include:

1. choice of stage versus elevation format;

2. selection of a clock time;
3. treatment of missing historical (gage) data;
4. generation of synthetic data; and
5. analysis period.

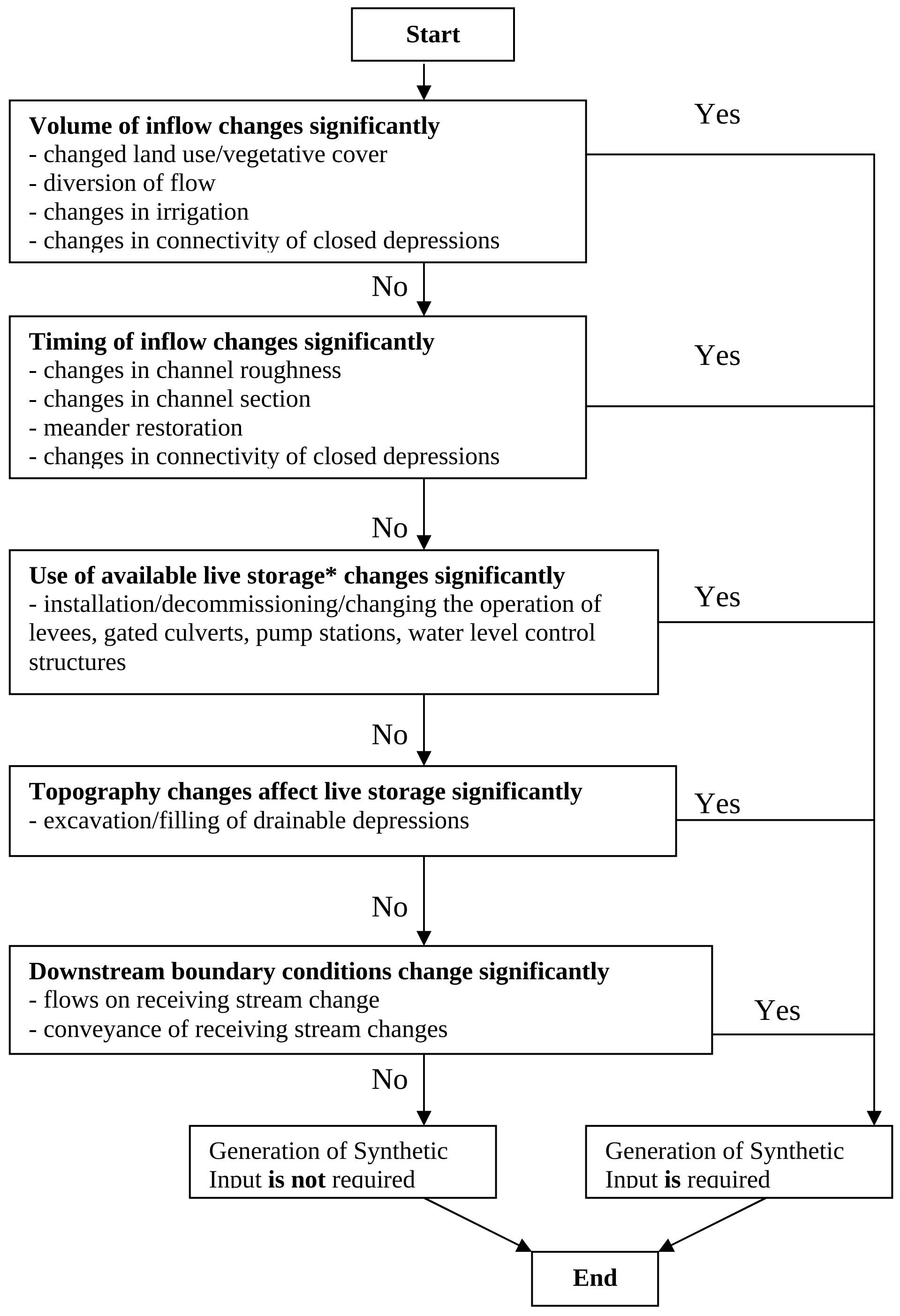
The format of historical gage data as stages or as elevations is not an issue, except for the requirement that the water surface and the topography be based on the same datum, since the differences between water surface and land surface elevations are the depths used in analysis. Since topographic data for the site will almost certainly be based on a datum related to sea level, and the conversion of stages of arbitrary datum to sea level elevations is very easy to accomplish, it is usually advisable to adopt an elevation format for water surface elevations.

Clock time for daily water surface elevation input is arbitrary, but should be held consistent throughout the period of record, if possible. For example, consider an EnviroFish analysis that will be based on a period of gage record that begins with a subset of years during which the gage was a staff gage read by eye once a day at 0800 hours, while during the remaining years in the period of record stages were collected mechanically on the hour. Suppose further that the 0800 readings are the daily stages that have been published in annual gage reports throughout the entire period of record. The selection of the 0800 stages for the entire period of record is not only the easiest approach, but also the approach that stakeholders will prefer as they compare EnviroFish output to published stage reports.

Missing data is not permitted in an EnviroFish analysis. Historical daily gage data should be checked for missing data prior to input to EnviroFish, and estimates of elevations should be entered for those dates on which data is missing. It is important to inform stakeholders about the flaws that are to be expected in historical data and to point out the necessity for interpretation of data in preparation of input to EnviroFish.

The EnviroFish approach may necessitate the synthesizing of water surface elevation input. Some project sites have no historic gage data. For some project sites the alternatives to be characterized are so unlike existing conditions that any available gage data is not usable for those alternatives. Situations that would likely require the synthesizing of water surface elevations include the installation of levees, gated culverts, water level control structures, pump stations, and alterations in the operation of existing facilities. The flowchart shown in Figure 5-1 illustrates how changes

in volume of inflow, timing of inflow, use of live storage, topography, and downstream boundary conditions can make it necessary to synthesize water surface elevations for a project alternative.



* The volume of water stored permanently in a depression is *dead storage*, since it does not affect routing--only volumes that can alternately store and release water affect routing computations and are referred to as *live storage*.

Figure 5-1. Flowchart of Alternative Changes Requiring the Generation of Synthetic Water Surface Elevation Input for EnviroFish.

Typically, water surface elevation input is synthesized by first using hydrologic techniques to estimate flows and hydraulic techniques to determine the resultant water surface elevations. In many cases, the hydrologic and hydraulic techniques are combined in a single computer program, because each day is a time step requiring a complete solution before the following day can be analyzed. Although EnviroFish only uses the dates within the spawning season, continuous hydrologic and hydraulic simulation must be performed on all days of the year for every year in the analysis period.

Unlike flood damage reduction studies, which emphasize the characterization of large, rare floods, the EnviroFish approach can emphasize the more frequent floods that maintain baseline populations of fish throughout their comparatively short lives. For this reason, the EnviroFish analysis period need not be as extensive as that to support flood damage reduction studies, although a long analysis period is certainly an advantage to reveal the effects of hydrologic variability. In all hydrologic and hydraulic modeling, there is uncertainty concerning the magnitude of computed data; the shorter the analysis period, the greater the uncertainty. However, the strength of the EnviroFish approach is its utility in characterizing the relative differences between project alternatives — as an aid in making decisions — despite uncertainty regarding water surface elevations. For many projects, an analysis period of 20 years should be sufficient to draw reliable conclusions from an EnviroFish analysis.

Pools and Flowlines

The EnviroFish approach assumes that although water surface elevations change from one day to the next, the water surfaces remain parallel to each other. Parallel water surfaces over time permit correct computation of the depths used to evaluate spawning and rearing. Level pools satisfy the parallel water surface assumption. In general, a stream flowline does not satisfy the parallel water surface assumption. Therefore, the application of EnviroFish to flowing streams necessitates the use of a suitable technique to minimize error.

Pooled water has a level surface. Pooled water sites may include man-made reservoirs, borrow pits, natural depressions, and sump areas on the land side of gated culverts or pump stations. Figure 5-2 shows, in plan and profile views, a sump area on the land side of a levee and culvert where water is ponded. Since the water surface is level, the edge of the pool

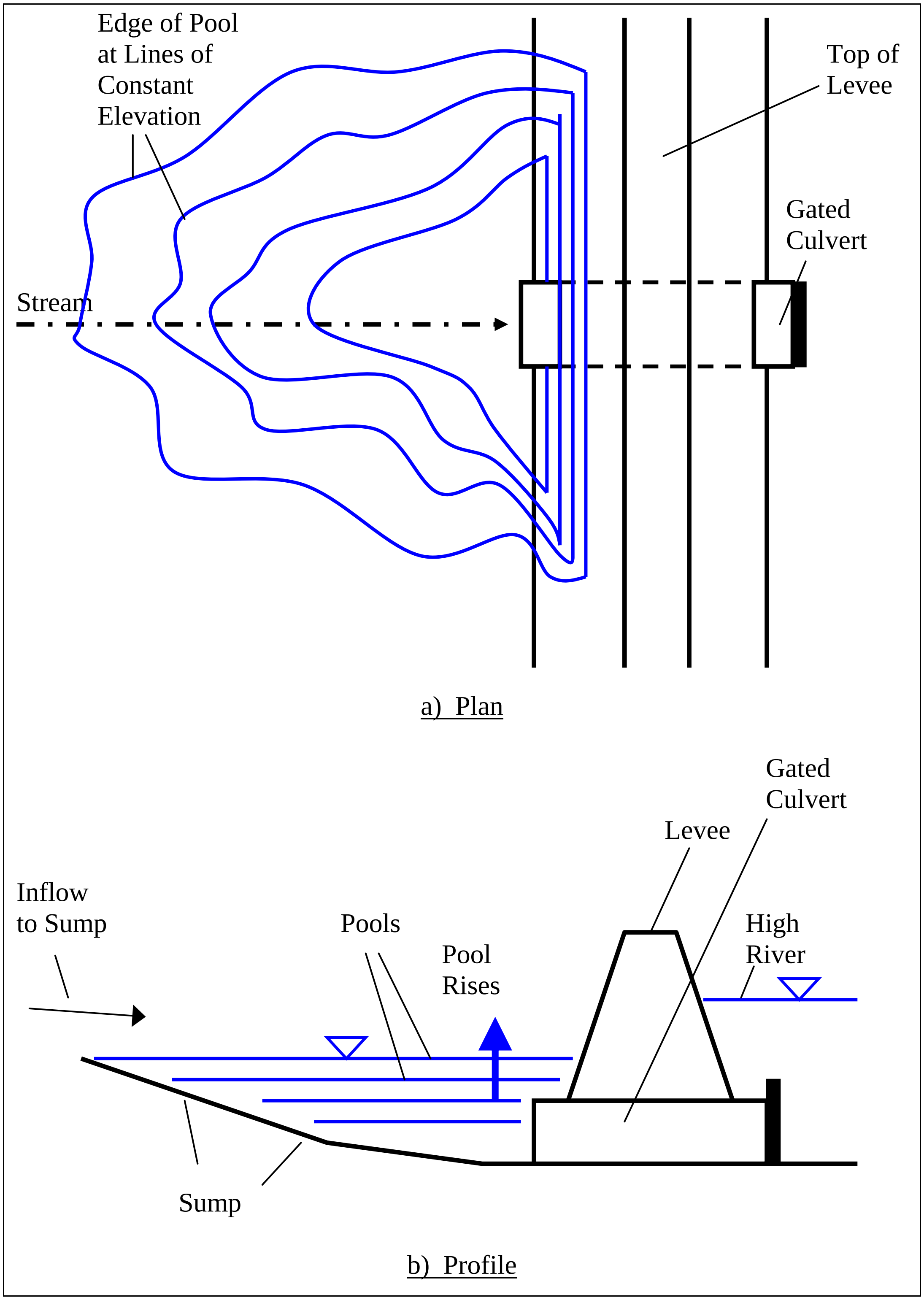


Figure 5-2. Profile of Pools at a Closed Culvert through a Levee.

coincides with a topographic contour. In this example, the culvert gate is shut against high river stages and the water surface on the land side rises as inflow to the sump occurs. In this situation, an elevation vs. area table accurately reflects the area of inundated land.

Even during a time when the river is low and the culvert gate is open, there may be cases where the pool upstream of the culvert is essentially level. For example, if the inflow rate is great enough, a pool may form at the sump. Also, if there is considerable area in the sump at, or below, the culvert invert elevation, a level pool may form in the sump even though water falls freely into the culvert inlet. Figure 5-3 shows the profile of a pool on the land side of an open culvert. In Figure 5-3 the lower two pools spill freely into the culvert, and the higher two pools submerge the culvert. The four pools are essentially level.

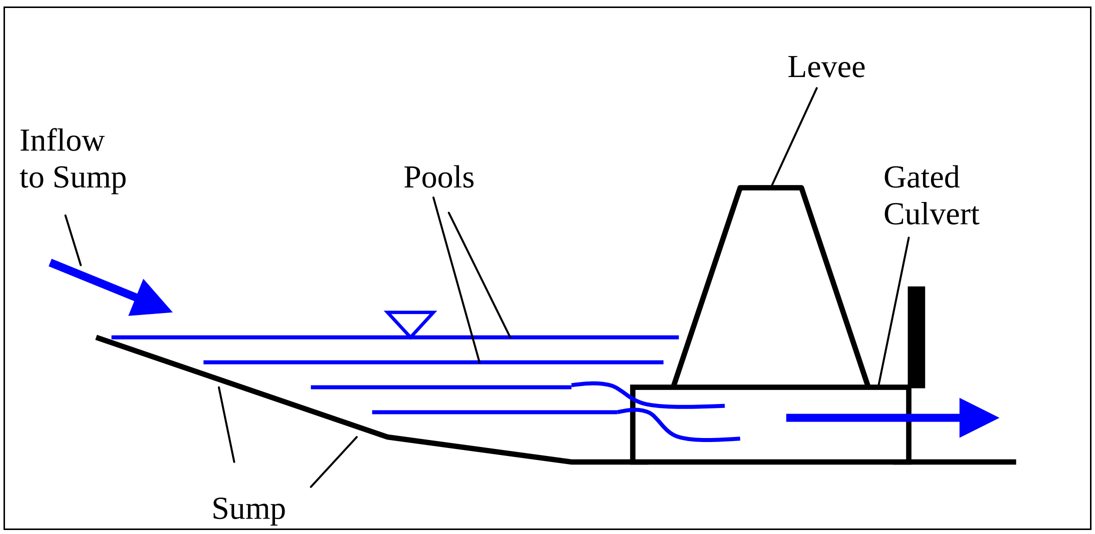


Figure 5-3. Profile of Approximately Level Pools at an Open Culvert through a Levee.

Level pools are simple cases. More complex situations for application of the EnviroFish approach involve flowing streams with water surface profiles, or flowlines, falling in the downstream direction. Flowlines can be inferred from the data gathered from a series of gages along a stream reach, or can be estimated using hydraulic computer models such as HEC-RAS. For a set of flowlines, the higher the elevation of the flowline, the greater the magnitude of flow. A set of flowlines along a river reach constitutes a family of curves, so named because adjacent flowlines closely resemble each other—much like the resemblance between two members of a family. In general, a family of flowlines is made up of individual flowlines that are not straight, not parallel to each other, and not parallel to the stream bed or to the valley floor.

The occurrence of strictly parallel flowlines along a stream is unlikely, but in a sufficiently short reach flowlines may occur that may be considered parallel within a margin of error. Figure 5-4 illustrates an idealized case of two flowlines, flowline 1 and flowline 2, that are parallel, although not parallel to the stream bed. The vertical distances at the downstream and upstream ends of the reach, $H_{d/s}$ and $H_{u/s}$, respectively, are equal. If flowline 1 occurs on a given day and flowline 2 occurs on the following day, then the EnviroFish assumption of parallel water surfaces from one day to the next is valid. Valley section views of the upstream and downstream ends of the valley reach are shown in Figure 5-5. The difficulty in applying EnviroFish to this situation is the requirement that the elevation vs. land area tables for each land use category must reflect sloping surfaces in the landscape, parallel to the flowlines. In an actual application, although flowlines that are closely spaced vertically may be nearly parallel, there is often an overall trend in flowline slope between the lowest flowlines that are confined to the channel and the highest flowlines that inundate the floodplain. Thus, a slope applicable to the channel may not apply to the floodplain. Furthermore, differences in alternatives may require the preparation of alternative-unique elevation vs. area tables for each land use category.

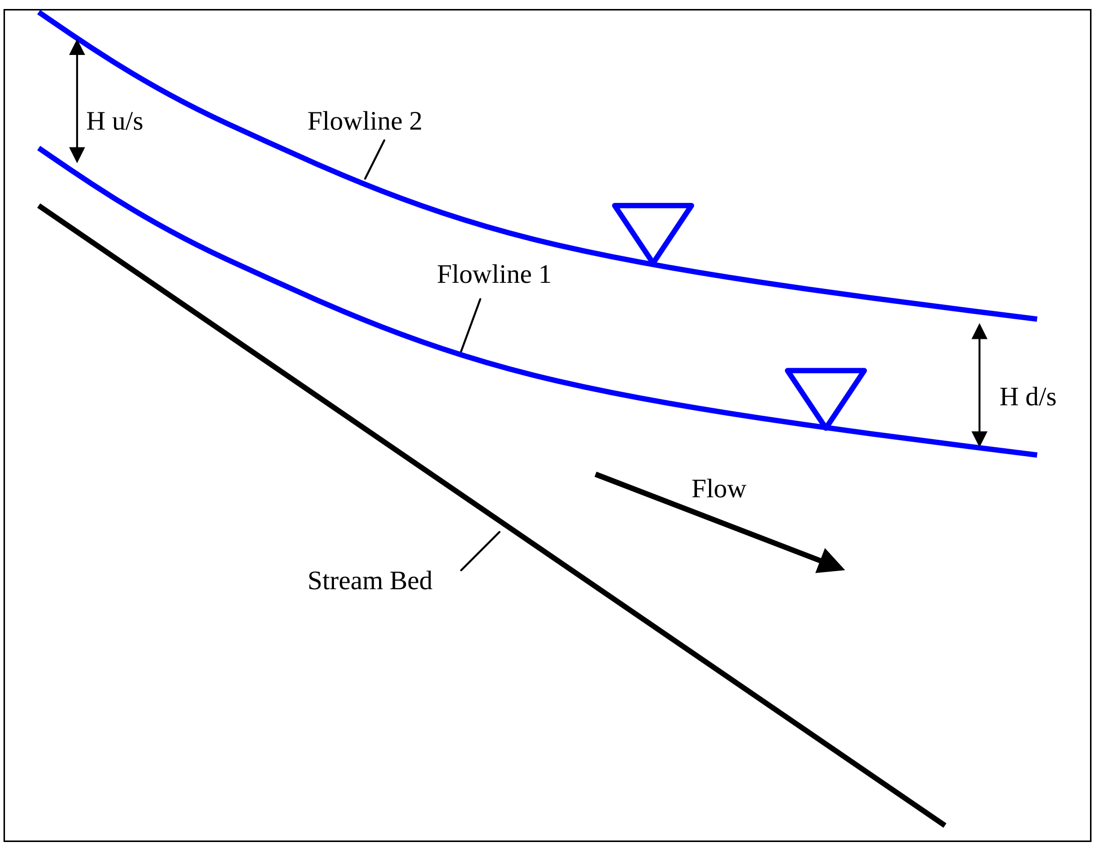


Figure 5-4. Profile of Parallel Flowlines in a Stream.

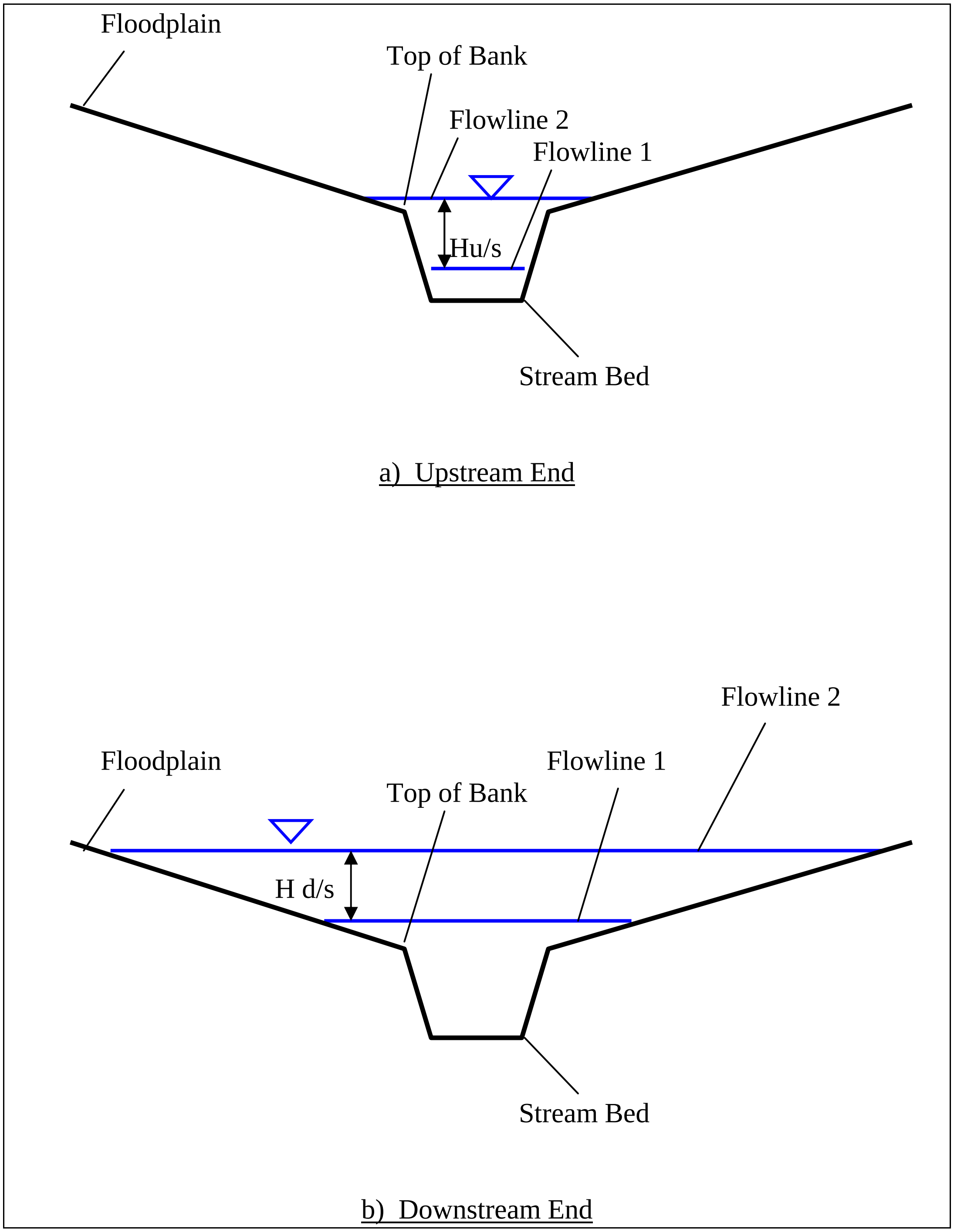


Figure 5-5. Valley Sections for Parallel Flowlines.

In the EnviroFish approach, greater difficulties arise with flowlines that are not parallel. As shown in the profile view of the stream reach in Figure 5-6, if the vertical distance, $H_{d/s}$, between flowline 1 and flowline 2 at the downstream end of the reach were 10 feet, the vertical distance, $H_{u/s}$, at the upstream end of the reach might only be 5 feet. If flowline 1 occurs on a

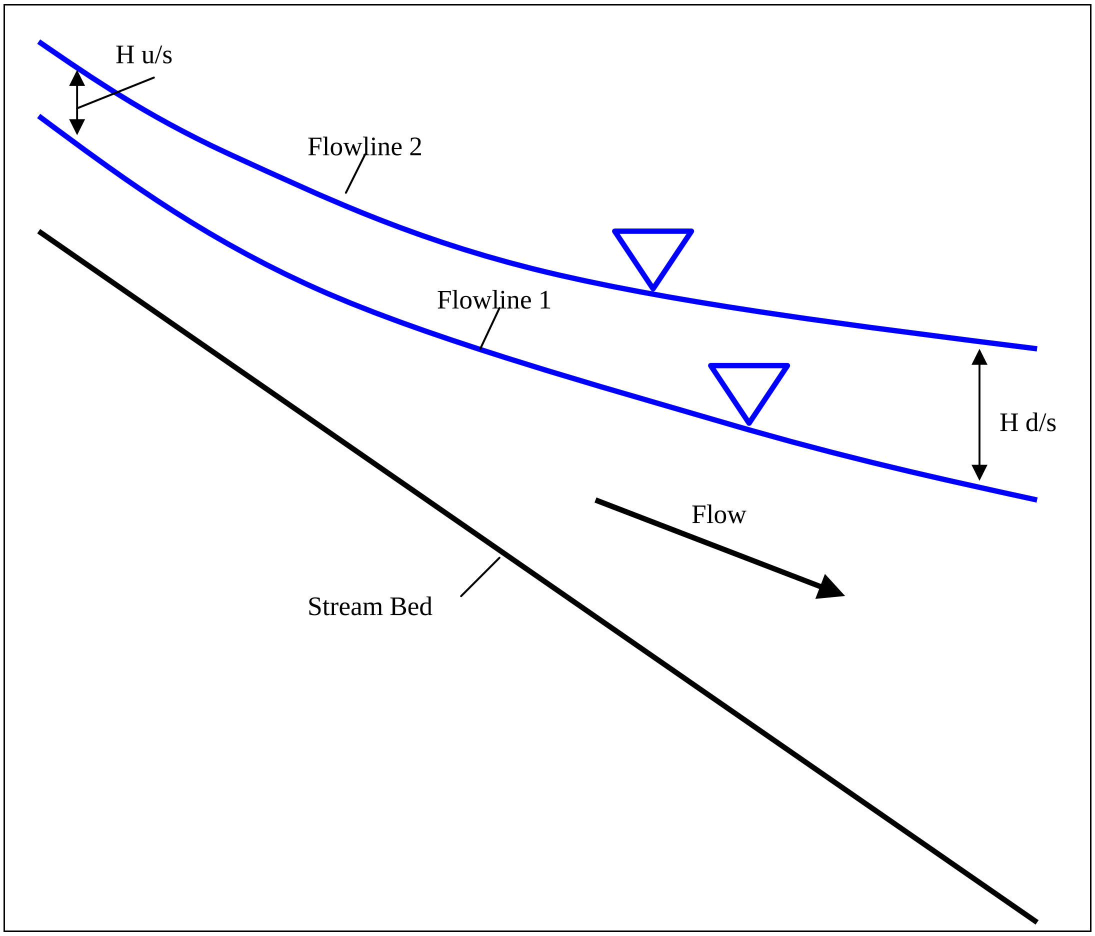


Figure 5-6. Profile of Non-Parallel Flowlines in a Stream.

given day and flowline 2 occurs on the following day, then the EnviroFish assumption of parallel water surfaces from one day to the next is not valid. Valley section views of the upstream and downstream ends of the valley reach are shown in Figure 5-7.

In view of such difficulties with non-parallel flowlines, perhaps the most practical approach is to divide the valley reach longitudinally into short segments. As shown in the profile view of a valley reach in Figure 5-8, the segments are short enough that the fall in the water surface from the upstream end to the downstream end is moderate and the water surface may be considered level within a margin of error. Daily water surface elevations are assigned to each segment and each segment is analyzed as a separate EnviroFish problem. Such an approach is laborious, but it can be taken to attain a specified degree of accuracy and makes use of conventional elevation vs. area tables that can be applied to all alternatives and can be readily understood by stakeholders.

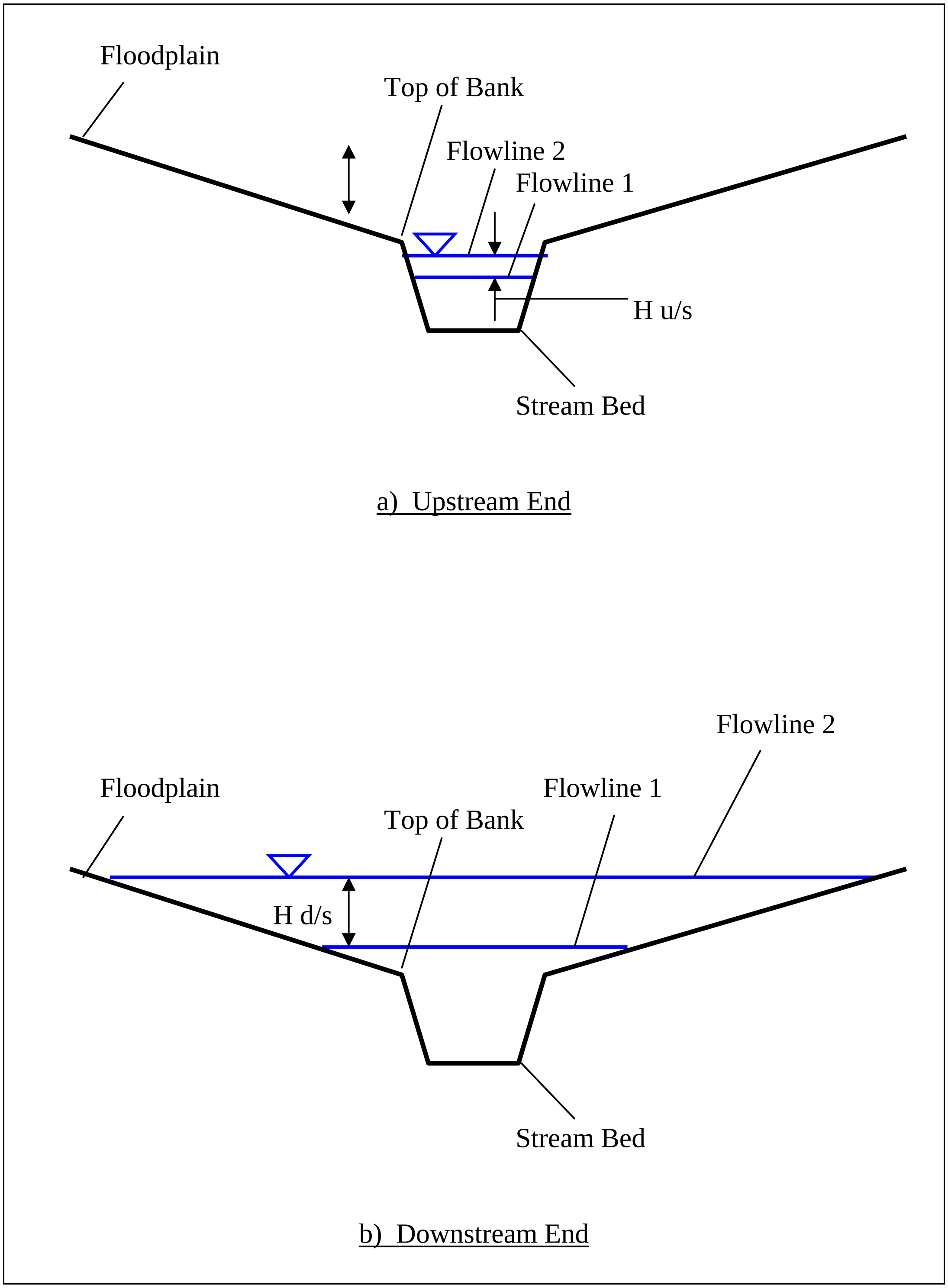


Figure 5-7. Valley Sections for Non-Parallel Flowlines.

Whatever technique is applied to dealing with pools and flowlines, cooperation between experienced hydraulic engineers, GIS personnel, and biologists is required to obtain a high quality product. Professional judgment, supported by iteration and sensitivity checks, is essential.

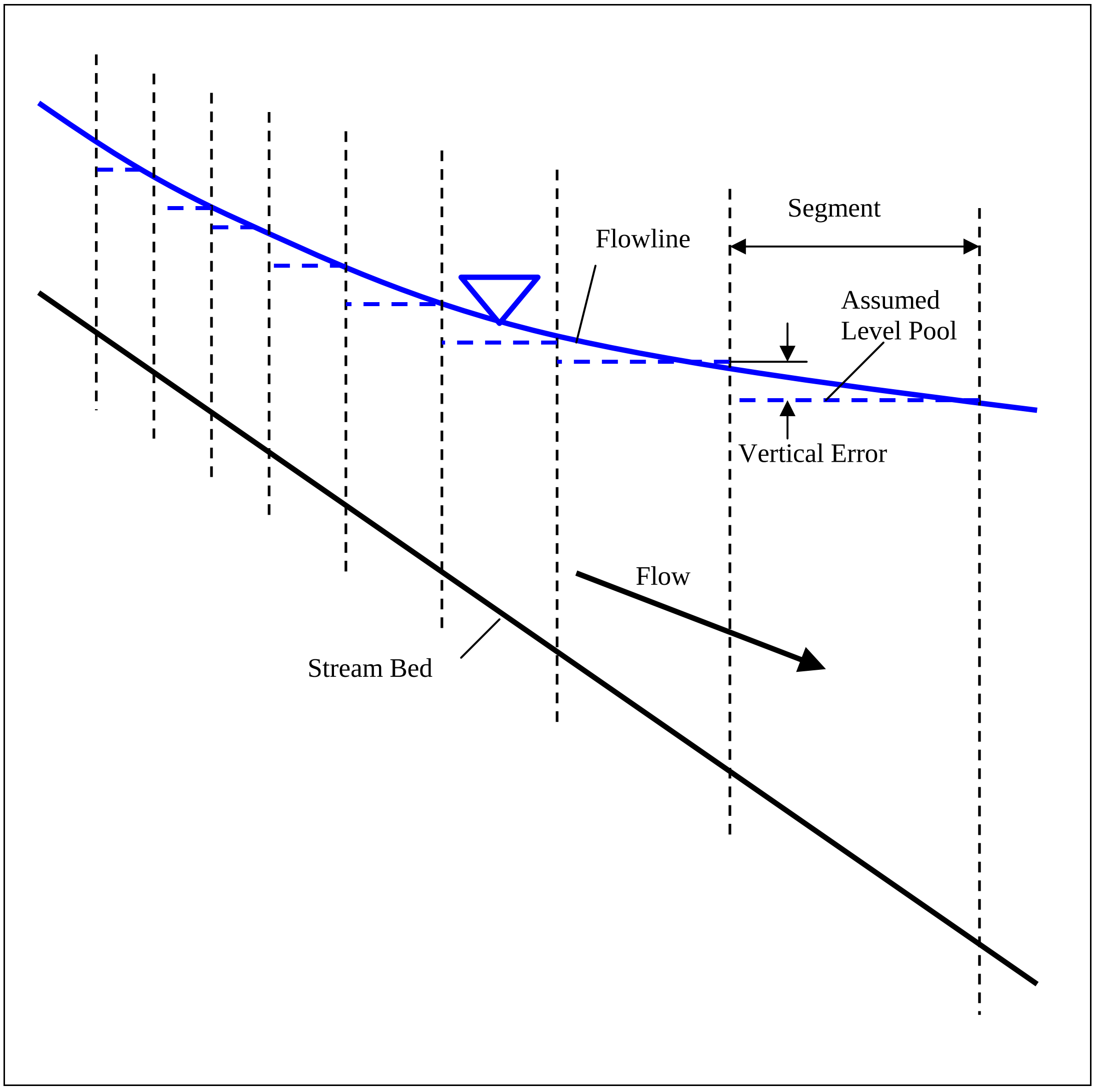


Figure 5-8. Profile of a Valley Reach Divided into Segments for Separate EnviroFish Analyses.

6 Example Problem

This chapter presents a simple example of using EnviroFish software. The example problem is based on a hypothetical landscape and hydrology. The landscape is an idealized surface of very simple geometry. Likewise, the water surface elevation input is idealized, exhibiting the least detail needed to illustrate the example. The example has been prepared in this way to emphasize the simple workings of the EnviroFish software itself, rather than the complexities of mapping and hydrology that may be encountered in an actual project. The EnviroFish input and output shown in Chapter 4 are taken from this example problem.

Setting

The example problem involves a flood damage reduction project, and the setting is a stream that is tributary to a larger river in an agricultural landscape. Both the scope of the flood damage reduction and the EnviroFish analysis are limited to the stream and its floodplain. Under existing conditions, there is no levee and no culvert. However, the levee and culvert are shown in all the site figures and are mentioned in the initial descriptions because they provide a downstream limit for the landscape to be analyzed. Two project alternatives are proposed. Alternative 1 consists of the installation of a levee and gated culvert. Alternative 2 is the same as Alternative 1, except a pump station is also included.

The project levee of Alternative 1 and Alternative 2 parallels the river and protects the floodplain of the stream from river flooding. A culvert through the levee allows the flow in the stream to join with the flow in the river whenever the culvert gate is open. The stream has a broad floodplain, which is subject to flooding from the stream in two situations. In the first situation, the river level is low and the culvert gate is open, but the flow in the stream is so great that flooding occurs. In the second situation, the culvert gate is shut against high river levels, and although the stream flow may be minimal, the floodplain eventually floods, simply due to the accumulation of headwater that cannot exit through the culvert. In this example, all flooding is treated as level pools.

As described in Chapter 4, the spawning season is March 1 through June 30. The spawning period is 8 days. The minimum and maximum allowable depths for spawning are 1.0 feet and 10.0 feet, respectively. The minimum and maximum allowable depths for restricted rearing are 0.1 feet and 11.0 feet, respectively. Both the "count orphaned areas" and "count deep areas" options are not checked, meaning that any departure from user-defined depth and duration criteria will not be counted.

Topography

The topography of the hypothetical site is designed to produce elevation contour outlines that are similar in shape and to facilitate calculations for elevation vs. area tables. The topography reflects existing conditions, and no changes in topography will occur for project alternatives.

As shown in a plan view of the landscape in Figure 6-1, the stream is straight and is perpendicular to the river levee, which is represented by a horizontal green line. The downstream end of the stream channel is at the levee culvert, represented as a red rectangle. The paired, parallel, vertical brown and red lines, symmetrical about the centerline of the stream, represent features of the channel, the floodplain, and the confining bluffs. These lines represent edges between sloping plane surfaces and are not level, but fall at a slope of 0.5 feet vertical per 1000 feet horizontal. (Referring to the section views in Figure 6.2 and the profile in Figure 6.3 should be helpful in following the description of these lines in plan view.) In Figure 6-1, the innermost pair of brown lines represent the corners of the stream channel bed. The pair of red lines represent the tops of the stream banks. The next pair of brown lines represent the toes of the confining bluffs. The left and right floodplains lie between the top of bank line and the toe of the bluff line. The outermost pair of lines are brown and represent the top lines of the bluffs. Having high bluffs along both edges of the landscape makes it easy to picture the floodwaters having a definite lateral limit. The total width of the left floodplain, channel topwidth, and right floodplain is 12,000 feet. The total width between the tops of the bluffs is 16,000 feet. The location where Section A-A and Section B-B cut across the channel and floodplain are shown by heavy black arrows. The distance between Section A-A and Section B-B is 50,000 feet. The dashed blue lines represent contour elevations at 505, 510, 515, 520, and 525 feet.

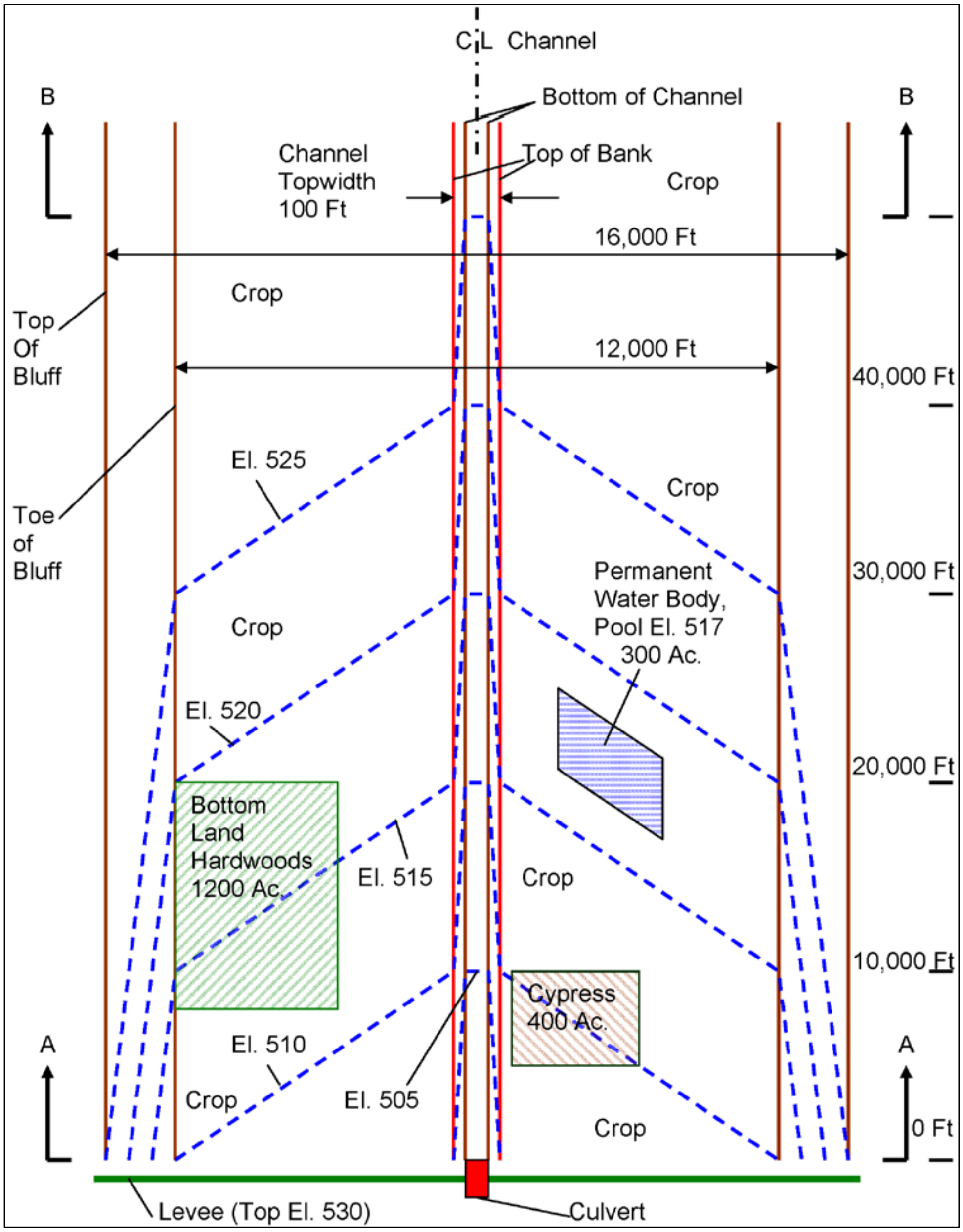


Figure 6-1. Plan View of Example Project Area.

Since flooding is being modeled as level pools, the contours are blue to emphasize that these contours are also flood outlines at these elevations. The shape of the contours can be understood by examining the contour segments for the 525 foot contour. The upstream-most segment of the contour is a horizontal line, which represents where the contour turns around in the bed of the stream. The segment is horizontal because the channel bed is level. Since the contour is symmetrical, it will suffice to examine only the branch of the contour on the right side of the figure. Proceeding down the page and downstream, the contour segment lies

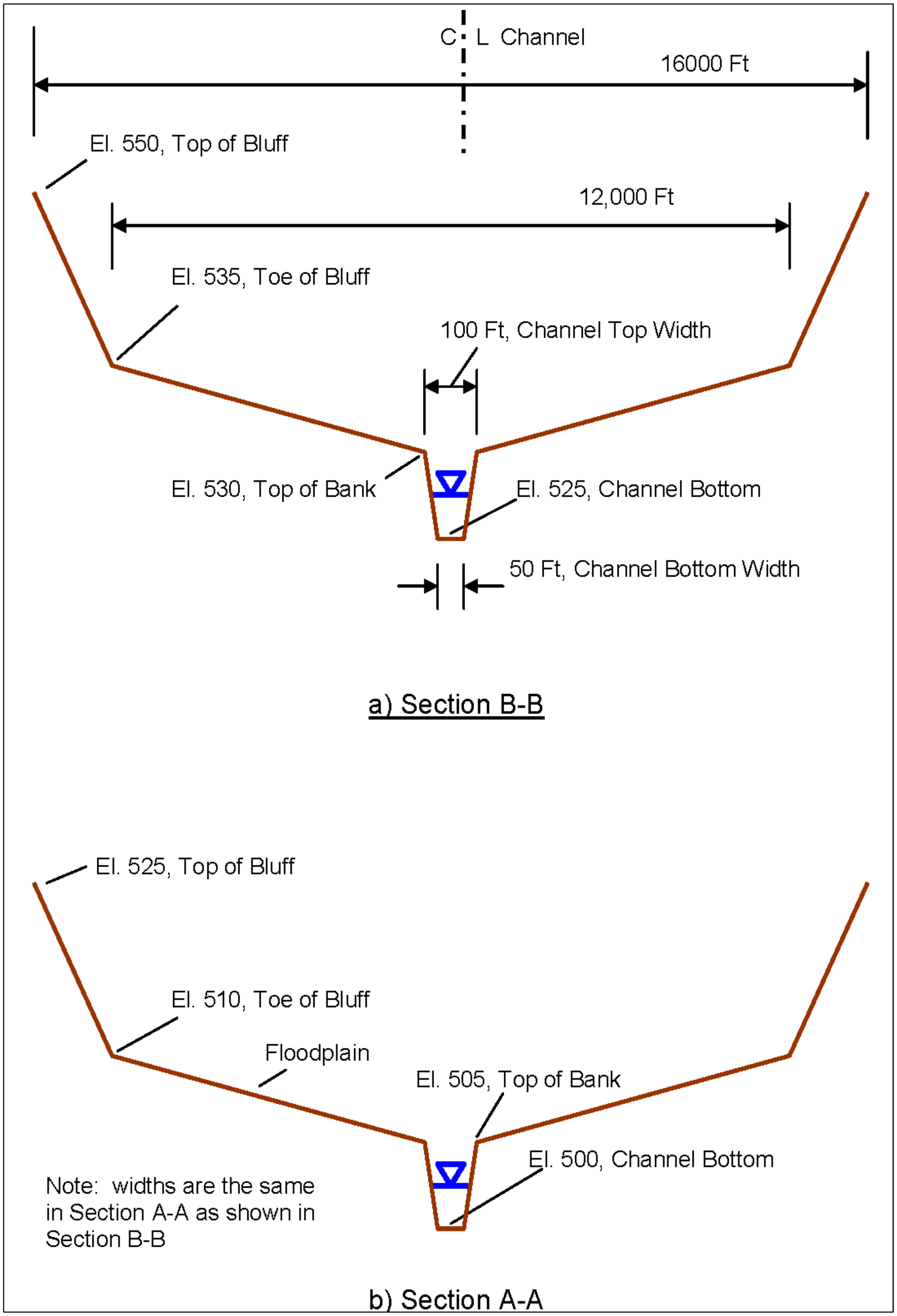


Figure 6-2. Sections of Example Project Area.

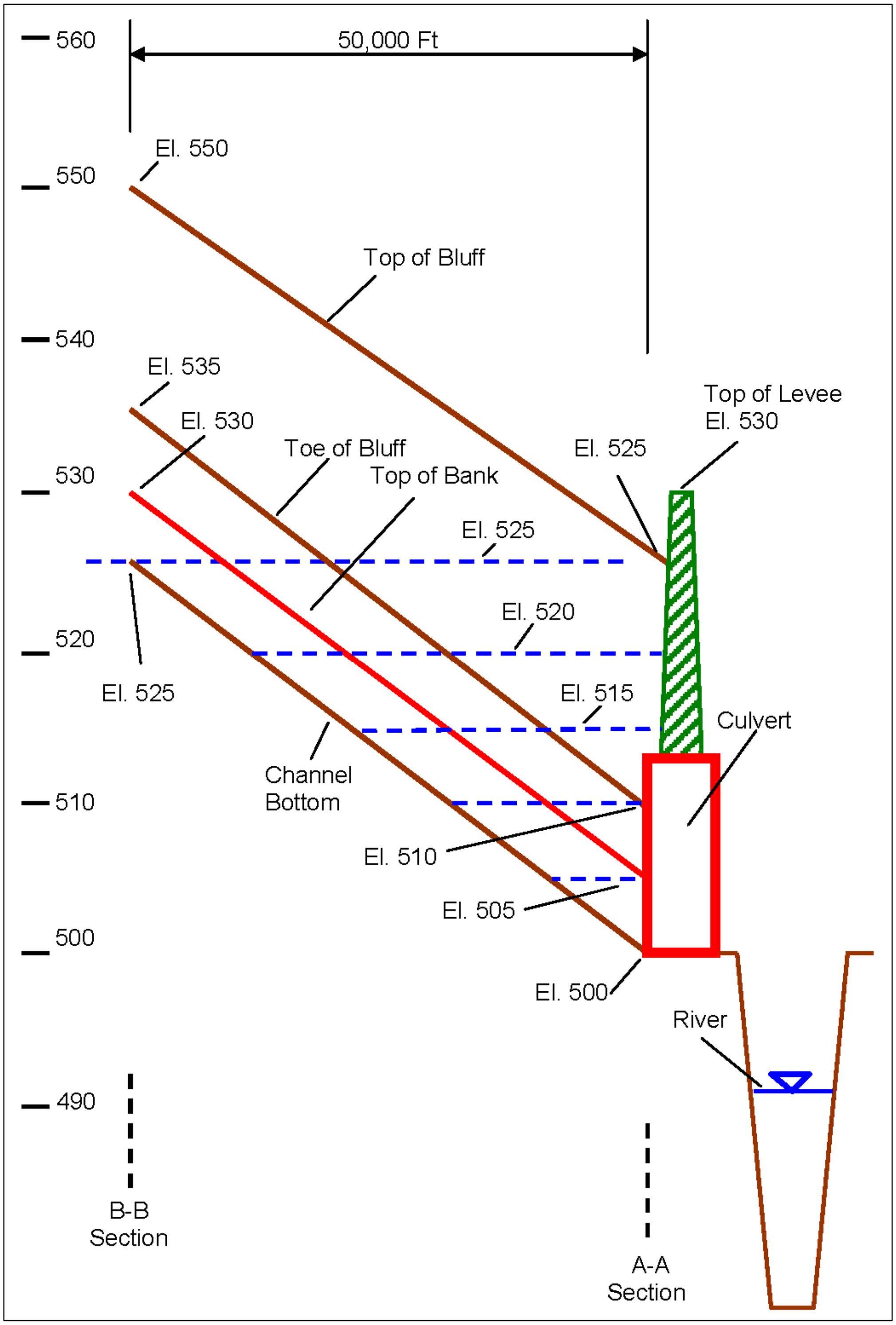


Figure 6-3. Profile View of Example Project Area.

within the channel to a distance of 40,000 feet from the levee, where it ends at the top of the channel bank. Another segment begins at the top of the bank and crosses the floodplain, ending at the toe of the bluff. A final

segment begins at the toe of the bluff and ends at the top of the bluff at the levee. The contours at lower elevations are geometrically similar to the 525-foot contour, except that the outmost contour segments are progressively truncated for the lower elevations. Although the stream channel and floodplain have a definite and abrupt end at the levee, the upstream end of the landscape has purposely been made indefinite, because it is the upstream extent of the flooding that governs, and this length may vary from day to day.

Two section views of the landscape are shown in Figure 6-2. Section A-A is perpendicular to the stream channel and is located at the downstream end of the landscape at the culvert. Section B-B is also perpendicular to the stream channel and is located 50,000 feet upstream of Section A-A. The size and shape of the two sections are the same. The elevations of the channel bed for Section A-A and Section B-B are 500 feet and 525 feet, respectively. Therefore, Section B-B is an exact copy of Section A-A, but translated 25 feet higher. The bottom width of the stream channel is 50 feet and the channel topwidth is 100 feet. The left and right floodplains slope uniformly toward the channel at 0.84 feet vertical per 1000 feet horizontal. The left and right bluffs slope uniformly toward the channel at 7.5 feet vertical per 1000 feet horizontal.

A profile view of the landscape is shown in Figure 6-3. The profile cuts through the levee and the culvert, which are shown in green and red hatched lines, respectively. The top of the levee is at elevation 530 feet. The invert of the culvert is at elevation 500 feet. To the far right, the river is also shown in section. The parallel lines in brown and red, sloping downward to the right, represent features of the channel, the floodplain, and the confining bluffs. The bottom sloping brown line represents the stream channel bed. The sloping red line represents the top of the channel bank. The next higher sloping brown line represents the toe of the bluff. The highest brown line represents the top of the bluff. The locations where Section A-A and Section B-B are cut across the channel and floodplain are indicated by heavy dashed lines near the bottom of the figure. The distance between Section A-A and Section B-B is 50,000 feet. The sloping lines are parallel to each other, having a slope of 0.5 feet vertical per 1000 feet horizontal. The horizontal dashed blue lines are lines of constant elevation at 505, 510, 515, 520, and 525 feet. These horizontal blue lines correspond to the blue dashed contour lines in Figure 6-1. Examining the top dashed horizontal line, which represents elevation 525 feet, it is evident that the contour intersects the top of the bluff at the levee. Progressing left on the

figure and upstream, it is also evident where the 525-foot contour intersects the toe of the bluff, the top of the channel, and the channel bed.

Land Use

A very simple example pattern of five land uses has been delineated in Figure 6-1, consisting of cropland, a cypress forest, a bottomland hardwood forest, and a single permanent waterbody. The cypress forest, delineated as a brown hatched rectangle, has an area of 400 acres and straddles the 510-foot contour. The bottom land hardwood forest (BLH), delineated as a green hatched rectangle, has an area of 1200 acres and straddles the 515-foot contour. The permanent waterbody, delineated as a blue hatched parallelogram, has an area of 300 acres lying between the 515-foot and 520-foot contours and has a surface elevation of 517 feet. The channel area, defined as all of the channel between left and right top of bank, has a rectangular shape in plan view and occupies 109.0 acres between the levee and a distance of 50,000 feet from the levee. All other land use is cropland.

A combined table of elevation vs. area for the five land uses is shown in Figure 6-4. The elevations range from 500 feet, which is the elevation of the stream channel bottom at the culvert, to 525 feet, which is the elevation of the stream channel bottom 50,000 feet upstream of the levee. The daily water surface elevations that will be input into EnviroFish are limited to this elevation range.

Examining the cypress forest area values in Figure 6-4, the highest elevation with a zero area of cypress forest is elevation 508 feet, which corresponds to the location of the bottom left corner of the rectangle, at approximately 508 feet. The lowest elevation having the maximum area of cypress forest, 400 acres, is elevation 512 feet, which corresponds to the location of the top right corner of the rectangle, at approximately 512 feet. Above elevation 512 feet, the values remain at 400 acres, emphasizing that the area values are cumulative rather than incremental.

Examining the bottomland hardwood forest area values in Figure 6-4, the highest elevation with a zero area of BLH forest is elevation 511 feet, which corresponds to the location of the bottom right corner of the rectangle, at approximately 511 feet. The lowest elevation having the maximum area of cypress forest, 1200 acres, is elevation 520 feet, which corresponds to the location of the top left corner of the rectangle, at 520 feet. Above elevation 520 feet the values remain at 1200 acres.

Elevation Feet	Area					
	Cypress Forest Acre	BLH Forest Acre	Permanent Water Body Acre	Channel Acre	Cropland Acre	Total Acre
500	0	0	0	0.0	0.0	0.0
501	0	0	0	2.5	0.0	2.5
502	0	0	0	5.5	0.0	5.5
503	0	0	0	9.0	0.0	9.0
504	0	0	0	12.9	0.0	12.9
505	0	0	0	17.2	0.0	17.2
506	0	0	0	21.8	54.6	76.4
507	0	0	0	26.4	218.5	244.9
508	0	0	0	31.0	491.7	522.7
509	50	0	0	36.6	823.2	909.8
510	200	0	0	40.2	1165.9	1406.1
511	350	0	0	44.7	1568.5	1963.2
512	400	50	0	49.3	2033.2	2532.5
513	400	200	0	53.9	2460.2	3114.1
514	400	300	0	58.5	2949.4	3707.9
515	400	600	0	63.1	3250.9	4314.0
516	400	800	0	67.7	3664.6	4932.3
517	400	900	0	72.3	4190.5	5562.8
518	400	1000	300	76.9	4428.7	6205.6
519	400	1150	300	81.5	4929.2	6860.7
520	400	1200	300	86.1	5541.8	7527.9
521	400	1200	300	90.6	6216.9	8207.5
522	400	1200	300	95.2	6904.0	8899.2
523	400	1200	300	99.8	7603.4	9603.2
524	400	1200	300	104.4	8315.1	10319.5
525	400	1200	300	109.0	9038.9	11048.0

Figure 6-4. Elevation vs. Area Table for Example Problem.

Examining the permanent waterbody area values in Figure 6-4, the highest elevation with a zero area of permanent water is elevation 517 feet, and the lowest elevation with the maximum area of 300 acres is at elevation 518 feet. Since the pool is level at elevation 517 feet, the area of the waterbody does not gradually increase with increasing elevation, as do land uses on sloping land. The shape of the waterbody was chosen as a parallelogram, so it would seem to fit neatly on contour between the contour lines of 515 feet and 520 feet. Since the resolution of the table is one foot, an arbitrary choice is made for the elevation at which to begin entering the area of the waterbody. The entries could properly begin at elevation 517 feet, rather

than at 518 feet. For an actual project, tables can be prepared to finer increments, such as 0.1 feet, and waterbody elevations may also be recorded to 0.1 feet, minimizing error.

Examining the channel area values in Figure 6-4, the highest elevation with a zero area of channel is elevation 505 feet, which corresponds to the downstream end of the channel at top of bank elevation. The maximum area of 109.0 acres corresponds to elevation 525 feet, which is the elevation of the channel bottom 50,000 feet upstream of the levee. Since the channel has a fixed width and falls at a uniform slope, the area of the channel accumulates linearly with increasing elevation. The area values are shown to the nearest 0.1 acre, due to the small cumulative values calculated for the lower elevations.

Examining the cropland area values in Figure 6-4, the highest elevation with a zero area of cropland is elevation 505 feet, which corresponds to the downstream end of the channel at top of bank elevation. The maximum area of 9038.9 acres corresponds to elevation 525 feet, which is the elevation of the channel bottom 50,000 feet upstream of the levee. The area values for cropland were calculated by subtracting all other land uses from the total landscape area.

The values in the rightmost column of the table in Figure 6-4 are the total area of the landscape at a given elevation and were calculated using a spreadsheet. The total values are not used as input to EnviroFish, since they reflect a mixture of land uses, but are only provided as an aid in understanding the example.

The elevation vs. area relationships for the five land uses and the total area are plotted in Figure 6-5. The plot emphasizes that the area in the channel is negligible below elevation 505 feet. The plot also emphasizes how the areas of forest and permanent water comprise only a small fraction of the total landscape, which is mostly cropland.

The EnviroFish computations for the example conclude with values of average daily flooded acres. To complete the example by calculating habitat quantities in Habitat Units, hypothetical habitat suitability indices for the five land uses are listed in Table 6-1. These values were selected simply to illustrate the use of EnviroFish and should not be interpreted as being necessarily applicable to a real project landscape.

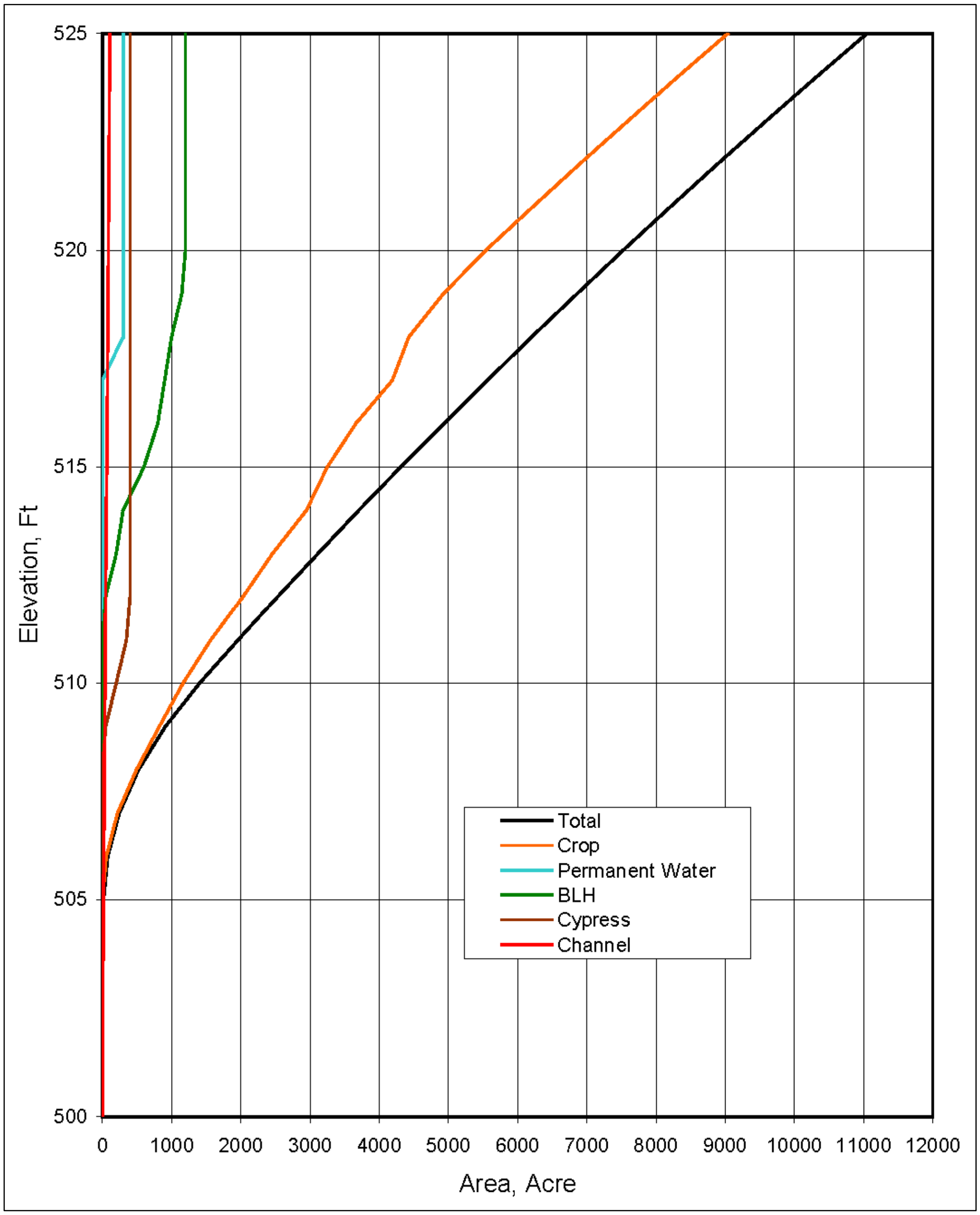


Figure 6-5. Elevation vs. Area for the Land Uses in the Example Problem.

Table 6-1. Habitat Suitability Indices for Example Problem.

Land Use	Habitat Suitability Index
Cypress Forest – small wetlands	0.9
BLH Forest	1.0
Large Floodplain Waterbody	0.8
Channel	0.5
Agricultural Cropland	0.2

Water Surface Elevations

Hypothetical daily water surface elevations have been developed for the three consecutive years of 2005 through 2007. The year 2005 is a very wet year, with severe flooding. The year 2006 features a normal range of water levels. The year 2007 is a very dry year, with no flooding.

Since the example is based on a spawning season of March 1 through June 30, the water levels input for the four months of the spawning season are realistically detailed, but the water levels for the other months of the year are shown constant throughout the month for simplicity. Plots of the daily elevation values for the example are shown in Figure 6-6. Figure 6-7, Figure 6-8, and Figure 6-9 are plots of daily elevation values for the years 2005, 2006, and 2007, respectively. These plots of water surface elevation versus time are called hydrographs. The solid red line represents the water elevation of the river at the confluence with the stream. The dashed green line represents the water surface elevation of the pool formed by flood water along the stream under existing conditions. The solid blue line represents the water surface elevation of the pool for Alternative 1 (installation of levee and gated culvert). The dashed brown line represents the water surface elevation of the pool for Alternative 2 (installation of levee, gated culvert, and pump station). Since some of the lines coincide at intervals, the dashed lines allow the solid lines to be visible between the dashes at some points.

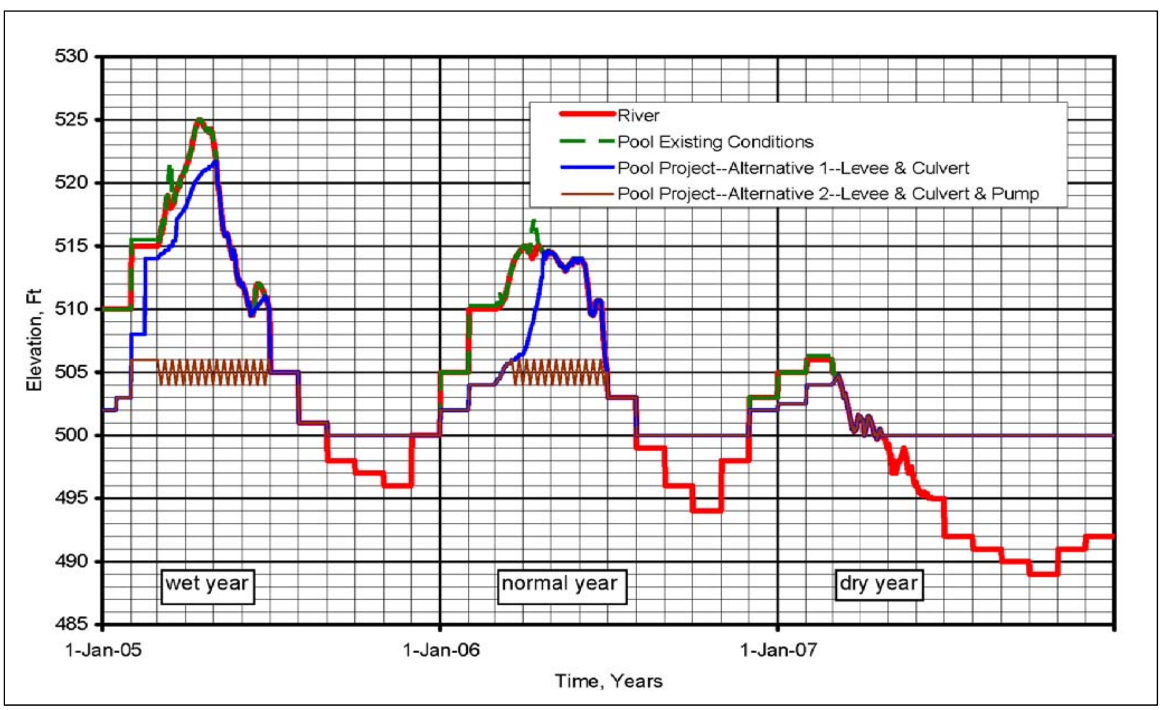


Figure 6-6. Example Hydrographs throughout 3-year Analysis Period.

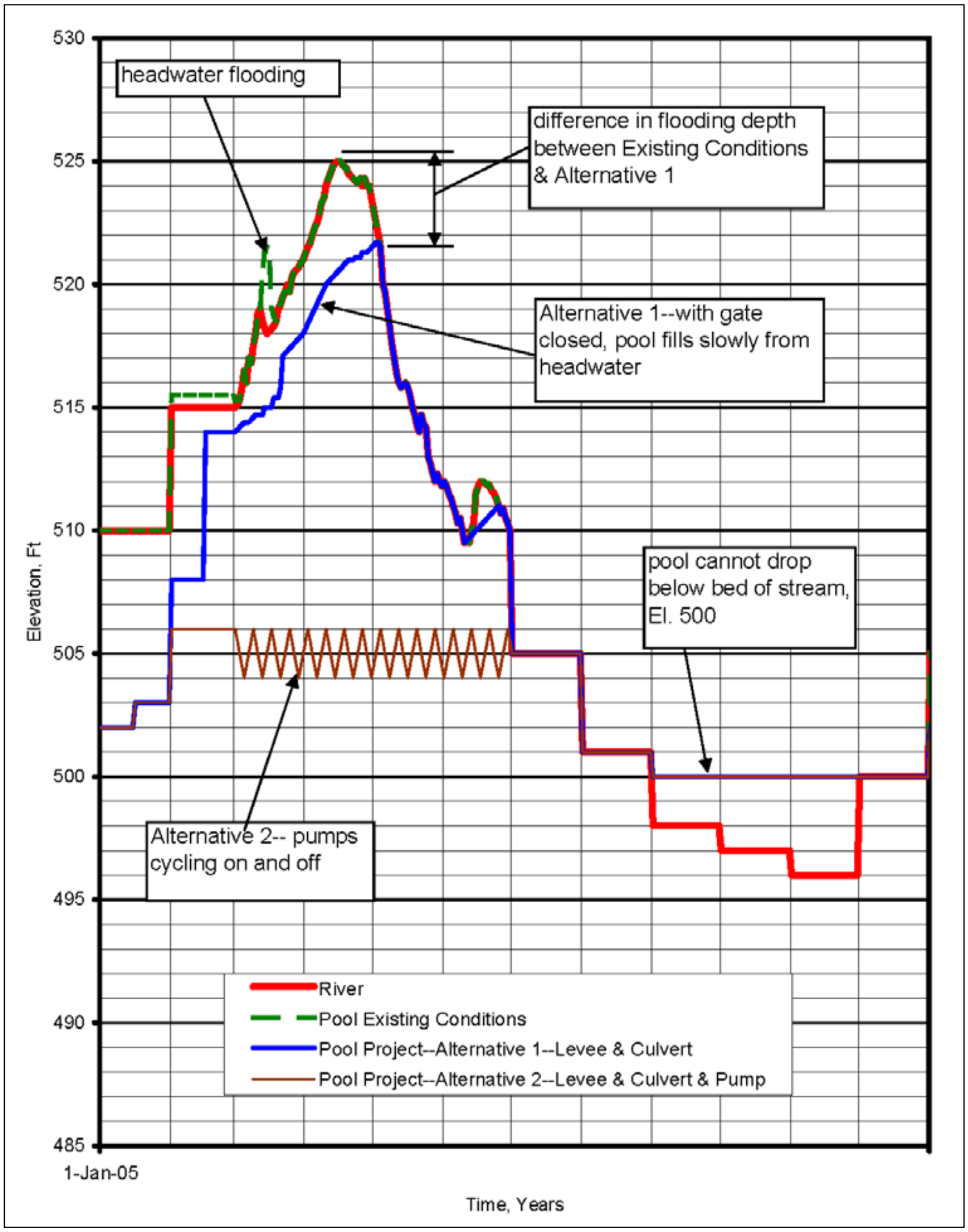


Figure 6-7. Example Hydrographs for Wet Year.

Under existing conditions, the water level in the river dominates the flooding in the stream floodplain. Without protection from a levee and a shut culvert gate, the flooding in the stream floodplain can never be lower than that in the river. This relationship is reflected by the fact that no curve in Figure 6-6 is lower than the red line.

Under existing conditions, water can occasionally rise to a higher level in the stream floodplain than that in the river. This is due to headwater flows in the stream channel being greater than what the channel can convey

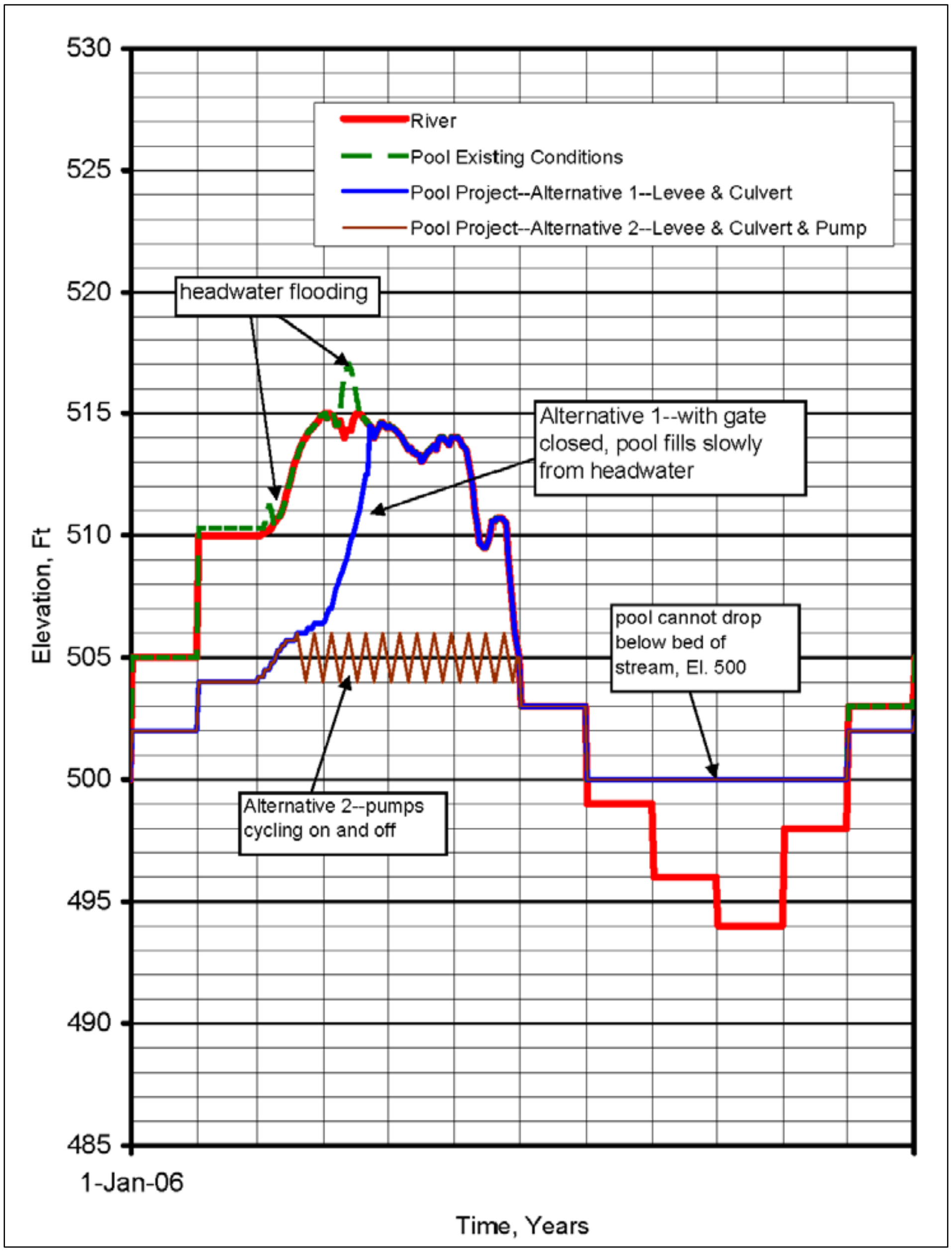


Figure 6-8. Example Hydrographs for Normal Year.

within its banks. Headwater flooding may occur in the stream floodplain whether the river level is high or low. The elevation spikes in the dashed green line for March, 2005 and for April, 2006 are signatures of headwater flooding within the project area.

Under project alternative 1, the stream floodplain is protected by the levee and the gated culvert from flooding by high river levels. However, with the culvert gate closed, accumulations of headwater runoff cannot be evacuated until the river falls, because there is no pump station. The signature of levee

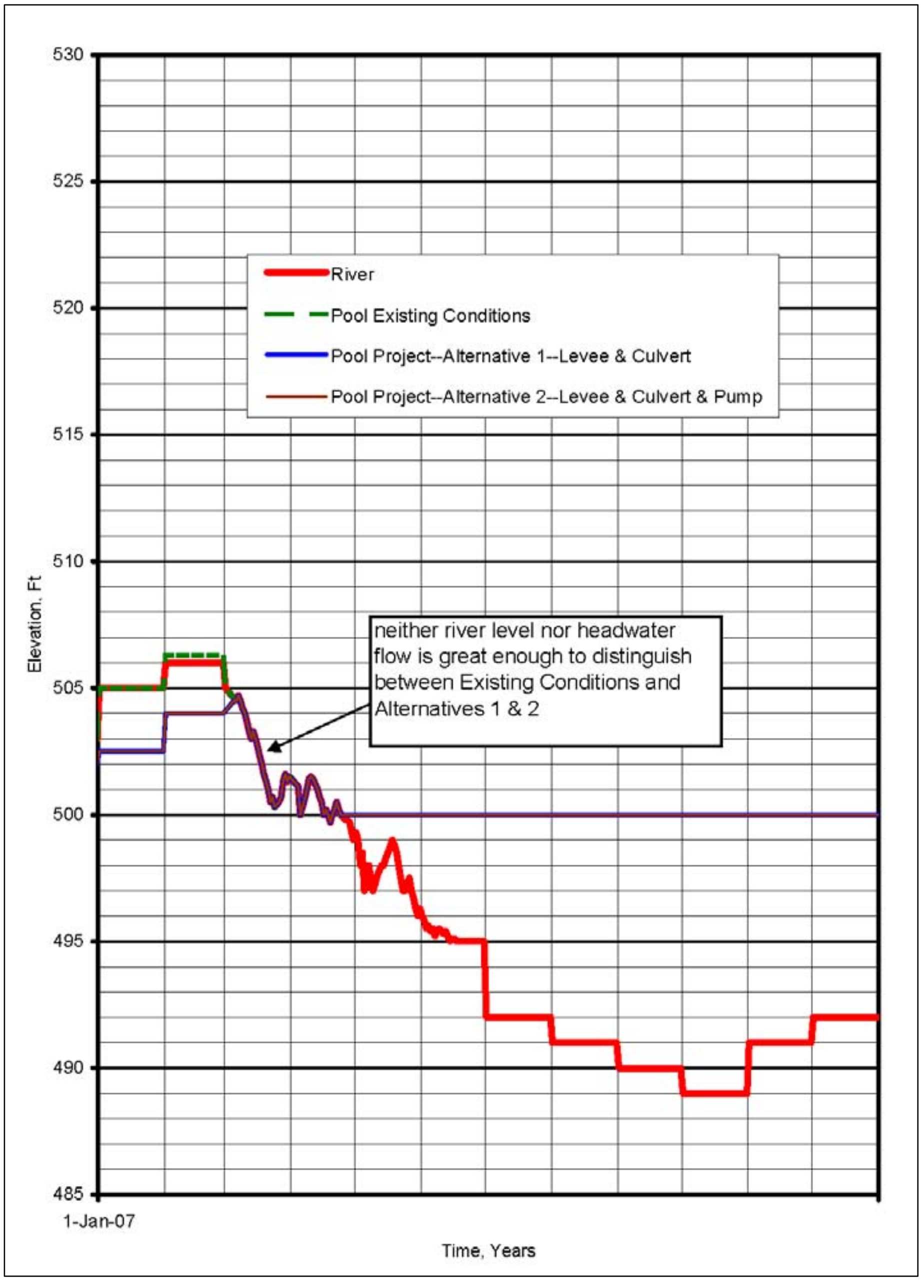


Figure 6-9. Example Hydrographs for Dry Year.

protection without pumping is the lagging rise of the blue line in March and April, 2005 and in April, 2006. In April, 2005 the pool level does eventually rise to the same level as the river (Elev. 522 feet), but it never attains the maximum level that would have occurred (Elev. 525 feet) without the levee at all. Since the river is falling on the date when the pool level matches the river level, the culvert gate is opened on that date and the pool level falls with the river level through May, 2005.

Under project alternative 2, the stream floodplain is protected by the levee and gated culvert from flooding by high river levels. Moreover, accumulations of headwater runoff can be evacuated in spite of high river levels, because there is a pump station. The signature of levee protection with pumping is the zigzagging of the brown line in March through June, in both 2005 and 2006. The pool hydrograph zigzags between elevation 504 feet and 506 feet because the pumps are set to come on at elevation 506 feet and to cut off at elevation 504 feet. For the pool elevation to never exceed the start pump elevation of 506 feet implies that the pumps have a great deal of capacity, and the example has been set up this way to keep the figure simple. For actual projects, the elevations would rise above the start pump elevation and gradually be brought down to the stop pump elevation, but a similar zigzag pattern would still be present.

EnviroFish Results and Interpretation

Loading the example input into EnviroFish and producing the output files are included in Chapter 4 and Chapter 5, respectively.

The EnviroFish program was run 15 times to generate the 15 values of ADFA listed in Table 6-2. For a given land use, the ADFA values listed in Table 6-2 are a maximum for existing conditions and a minimum for Alternative 2. The values for Alternative 1 are on the same order of magnitude as those for Existing conditions, but the values for Alternative 2 are essentially 1 to 2 orders of magnitude smaller than those for existing conditions. The example was intentionally designed to provide large differences between alternatives, and the results shown in Table 6-2 should not be interpreted as necessarily typical for actual projects. The ADFA values shown in Table 6-3 are for restricted rearing and show the same proportions as spawning between existing conditions, alternative 1, and alternative 2. However, the values are larger than the values for spawning, because the range of depths (0.1 ft to 11.0 ft) is less restrictive than for spawning (1.0 ft to 10.0 ft). The ADFA values shown in Table 6-4 are for total rearing and also show the same proportions as spawning between existing conditions, alternative 1, and alternative 2. The values are larger than the values for restricted rearing, because the range of depths (0.0 ft to unlimited depth) is less restrictive than for restricted rearing (0.1 ft to 11.0 ft). The ADFA values shown in Table 6-2, Table 6-3, and Table 6-4 are the concluding output of EnviroFish for this example problem. At this point, Average Daily Flooded Area by land use category can be copied to a spreadsheet to calculate Habitat Units.

Table 6-2. EnviroFish Spawning ADFA Values for the Analysis Period of 2005 – 2007.

Land Use	Existing Acre	Alternative 1 Acre	Alternative 2 Acre
Cypress Forest	134.1	120.4	0
BLH Forest	192.7	167.6	0
Large Permanent Waterbody	38.5	23.2	0
Channel	21.3	20.0	6.3
Cropland	1350.2	1074.4	0

Table 6-3. EnviroFish Restricted Rearing ADFA Values for the Analysis Period of 2005 – 2007.

Land Use	Existing Acre	Alternative 1 Acre	Alternative 2 Acre
Cypress Forest	200.1	178.5	0
BLH Forest	316.9	243.9	0
Large Permanent Waterbody	49.8	35.2	0
Channel	32.2	28.9	12.0
Cropland	2069.8	1576.5	7.9

Table 6-4. EnviroFish Total Rearing ADFA Values for the Analysis Period of 2005 – 2007.

Land Use	Existing Acre	Alternative 1 Acre	Alternative 2 Acre
Cypress Forest	242.9	194.5	0
BLH Forest	338.3	249.5	0
Large Permanent Waterbody	50.1	36.1	0
Channel	43.5	36.4	12.3
Cropland	2370.7	1704.4	9.3

EnviroFish ADFA values are multiplied by the HSI values to obtain HUs for each land use. The sum of the HSI for all land uses is the total HUs for a project alternative. The multiplication can be performed in a simple computer spreadsheet, as shown in Figure 6-10. Figure 6-10 lists the HSI used, the ADFA by land use and alternative, the calculated HUs, and the totals of the HUs. A comparison of the spawning existing conditions ADFA values with the HUs for cropland and BLH emphasizes how a high value land use of small area can provide habitat value equivalent to a low value land use of large area.

The HU values listed in Table 6-5 are present in bar-chart form in Figure 6-11. For all three alternatives, HUs increase at a decreasing rate for spawning, restricted rearing, and total rearing. The HUs for alternative 1

are more than half the HUs for existing conditions, but the HUs for alternative 2 are negligible. This extreme example illustrates how a project alternative that would totally prevent overbank flooding would negate the spawning and rearing opportunities that the floodplain would otherwise afford.

Habitat Suitability Indices

Land Use	HSI
cypress	0.9
blh	1.0
water	0.8
channel	0.5
crop	0.2

Spawning Habitat

Land Use	Existing Conditions		Alternative 1		Alternative 2	
	ADFA	HU	ADFA	HU	ADFA	HU
	acre	acre	acre	acre	acre	acre
cypress forest	134.1	120.7	120.4	108.4	0.0	0.0
BLH	192.7	192.7	167.6	167.6	0.0	0.0
permanent water	38.5	30.8	23.2	18.6	0.0	0.0
channel	21.3	10.7	20.0	10.0	6.3	3.2
cropland	1350.2	270.0	1074.4	214.9	0.0	0.0
HU Totals :		**624.9**		**519.4**		**3.2**

Restricted Rearing Habitat

Land Use	Existing Conditions		Alternative 1		Alternative 2	
	ADFA	HU	ADFA	HU	ADFA	HU
	acre	acre	acre	acre	acre	acre
cypress forest	200.1	180.1	178.5	160.7	0.0	0.0
BLH	316.9	316.9	243.9	243.9	0.0	0.0
permanent water	49.8	39.8	35.2	28.2	0.0	0.0
channel	32.2	16.1	28.9	14.5	12.0	6.0
cropland	2069.8	414.0	1576.5	315.3	7.9	1.6
HU Totals :		**966.9**		**762.5**		**7.6**

Total Rearing Habitat

Land Use	Existing Conditions		Alternative 1		Alternative 2	
	ADFA	HU	ADFA	HU	ADFA	HU
	acre	acre	acre	acre	acre	acre
cypress forest	242.9	218.6	194.5	175.1	0.0	0.0
BLH	338.3	338.3	249.5	249.5	0.0	0.0
permanent water	50.1	40.1	36.1	28.9	0.0	0.0
channel	43.5	21.8	36.4	18.2	12.3	6.2
cropland	2370.7	474.1	1704.4	340.9	9.3	1.9
HU Totals :		**1092.9**		**812.5**		**8.0**

Figure 6-10. EnviroFish ADFA Output and Resultant HU Values.

Table 6-5. EnviroFish Habitat Units for the Analysis Period of 2005 – 2007.

Land Use	Existing Acre	Alternative 1 Acre	Alternative 2 Acre
Spawning	624.9	519.4	3.2
Restricted Rearing	966.9	762.5	7.6
Total Rearing	1092.9	812.5	8.0

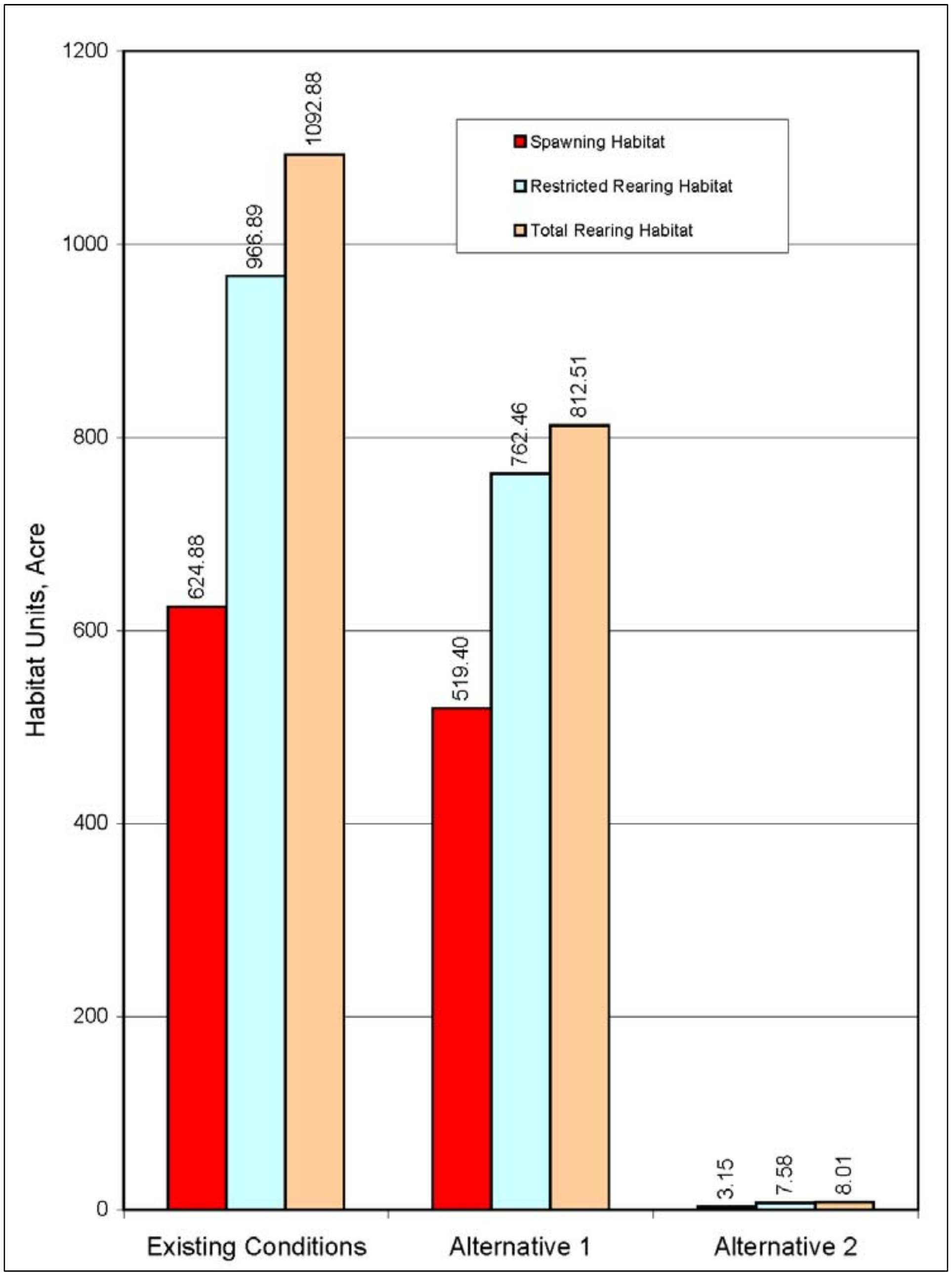


Figure 6-11. Habitat Units for Example Problem Alternatives.

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Appendix A: HEC Modeling Software

The successful use of the EnviroFish approach depends heavily on the use of hydrologic and hydraulic software to prepare input. Although the EnviroFish user may not become directly involved in the hydrologic modeling, a general awareness of the available approaches to hydrologic modeling, and the strengths and weaknesses of the various approaches, is needed to plan a feasible EnviroFish analysis. This appendix provides a brief overview of the U.S. Army Corps of Engineers hydrologic software developed by the Hydrologic Engineering Center (HEC) in Davis, California.

HEC Software

The three HEC computer programs that the EnviroFish user should be aware of include:

1. the Hydrologic Modeling System (HMS);
2. the River Analysis System (RAS); and
3. the Interior Flood Hydrology (IFH).

Programs evaluate different features of water management:

Features of the Different HEC Software Programs				
Feature	HEC IFH	HEC HMS	HEC RAS Unsteady	Demo Level Pool
Continuous simulation of rainfall-runoff		X		X
Level pool routing	X	X		X
Pool evaporation loss				X
Pool seepage loss				X
Culvert hydraulics	X		X	X
Weir hydraulics		X	X	X
Levee seepage	X			X
Gated culverts	X		X	X
Gated culverts with seasonally controlled opening rules				X
Gated culverts with seasonal control to hold habitat pool on land side				X
Pump stations (flood control)	X	X	X	X
Well pumps (water supply) controlled by elevation & season				X
Seepage wells (water supply)				X
Flashboards controlled by season				X
Daily water surface profiles			X	

References for these programs:

USACE. 1993. Engineering and Design – Hydrologic Frequency Analysis. EM 1110-2-1415. Washington DC: U.S. Army Corps of Engineers.

USACE. 2008. HEC RAS River Analysis System User's Manual, Version 4.0. Davis, CA: Hydrologic Engineering Center.

Hydrologic Versus Hydraulic Modeling Software

Hydrologic modeling software estimates volumes and flows, and hydraulic modeling software estimates the energy losses associated with known flows. Flow is the rate of water movement, expressed as a volume per unit time, such as cubic feet per second. Hydrologic software may model rainfall depth, depth of runoff, runoff volumes accumulated in reservoirs, and the flows in channels. Hydraulic software may apply known channel flows to estimate how high the water surface is in a channel, whether flow occurs in the floodplain, whether flood water overtops a road, or how much horsepower is required by a pump. In practice it is difficult to keep hydrology and hydraulics separate, because the hydrologic aspects of a system must be known to characterize the hydraulic aspects, and the hydraulic aspects of the system must be known to characterize the hydrologic aspects. In some cases iteration is required between hydrologic and hydraulic software to arrive at input that is hydrologically and hydraulically consistent.

Appendix B: Data Storage System (DSS)

EnviroFish accepts some of its input only in a Data Storage System (DSS) file format. Version 1.2.10b of HEC-DSSVue must be used with EnviroFish software. Specifically, the elevation vs. land area input for each land use type and the daily water elevation input must both be stored in a single DSS file prior to an EnviroFish program run. The spawning and rearing constraints input data are not stored in DSS, but data are entered from the keyboard into the EnviroFish main window.

DSS is a hydrologic data management software, rather than a modeling software, and was developed by the Corps of Engineers Hydrologic Engineering Center (HEC) in Davis, California. DSS can be used to store historical hydrologic data collected from gages or other instruments. DSS can also be used to store input into, and output from, hydrologic and hydraulic models. Within a Corps of Engineers district setting, the hydrologic/hydraulic modeler is likely to be the person who stores the model results in a DSS file for use as input into EnviroFish.

DSS Paths

DSS information is organized by paths. A path name may have six descript-tive parts, known as A, B, C, D, E, and F. Part A is used to name the river basin or project name. Part B is used to name a location. Part C identifies the data variable. Part D identifies the starting date for time series data. Part E identifies the time step for time series data. Part F is an additional descriptor. Paired data makes different use of the D and E parts.

Each EnviroFish elevation vs. area table for a land use is identified by a unique path name. In the example problem of Chapter 6, there are five elevations vs. area paths because there are a total of five land uses in the problem.

In the example problem of Chapter 6, each combination of a calendar year of daily water surface elevation with a project alternative is identified by a unique path name. There are 15 paths for water elevation in the example problem, because there are three years of water elevation input and five land uses (3 x 5 = 15). This is necessary because the random, climatic

variability of the three historical years must be related to the systematic behavior associated with the different project alternatives.

Paired Data

The information in an elevation vs. area table is referred to as paired data, in the sense that the two variables can be plotted as coordinate pairs, x and y, having no reference to time. In the example problem of Chapter 6, the elevation vs. land area part names are A=ANY RIVER BASIN, B=ANY POOL, C=ELEV-AREA, D= (blank), E= ELEVATION-AREA CURVE, and F=BLH, etc. The user chooses the wording of the entries for Parts A, B, and F. An entry for Part E is optional, and is a freely worded description. The entries for C should not be freely worded, but should be a pair of hyphen-separated words selected from a list of DSS terms.

Time Series Data

The water surface elevation input used by EnviroFish is referred to as time series data, in the sense that a single variable, elevation, is ordered with respect to time. In the example problem of Chapter 6, the water surface elevation part names are A=ANY RIVER BASIN, B=ANY POOL, C=ELEV D= 01JAN2005.., etc, E= 1 DAY, and F=ALT 1, etc. The user chooses the wording of the entries for Parts A, B, C, and F. The entries for Part D and E must be chosen from a list of DSS terms. "ELEV" is the recommended Part C entry for use with EnviroFish. EnviroFish is coded to make use of daily water surface elevation input only. Therefore, the Part E entry must be "1 DAY" only. Entries for Part E depend on the beginning calendar year of input, but should use the date format "ddmmmyyyy," such as 01JAN2005.

DSS User Manuals

The following four DSS user's manuals, are available for web download from HEC:

1. *HEC-DSS User's Guide and Utility Manuals*, CPD-45. (Corps 1995)
2. *HECLIB Volume 1: HECLIB Subroutines, Programmer's Manual*, CPD-58. (Corps 1987)
3. *HECLIB Volume 2: HECDSS Subroutines, Programmer's Manual*, CPD-57. (Corps 1991)
4. *HEC Data Storage System Visual Utility Engine User's Manual (DSSVue)*, Version 1.2, CPD-75. (Corps 2005).

The *HEC-DSS User's Guide and Utility Manuals* is the basic introduction to DSS for users such as hydrologists and hydraulic engineers. Although written for pre-windows operating environments, the methods described in the *User's Guide* are applicable to the current uses of DSS. Many users of EnviroFish would benefit by referring to this manual, since it provides a broad picture of the requirements for a hydrologic database and explains why DSS operates as it does.

HECLIB Volume 1 and *HECLIB Volume 2* were written for pre-windows operating environments and are written for hydrologists, hydraulic engineers, and computer programmers. These manuals describe how DSS stores and retrieves information, and how routine calculations are executed. These manuals are extremely detailed and are unlikely to be helpful to the non-programmer.

Most users of EnviroFish would benefit greatly by referring to the *DSSVue* manual. *DSSVue* is a windows software that facilitates the viewing, inputting, and editing of information in DSS files. *DSSVue* can present information in either tabular or graphical formats. There is not a substitute for using *DSSVue* in the windows environment. For example, the information stored in a DSS file cannot be edited with a text editor.

Appendix C: EnviroFish Calculations

This appendix describes EnviroFish calculations in greater detail than is provided in the main body of the manual.

In all cases, EnviroFish calculates averages as the arithmetic mean. No use is made of the median in EnviroFish.

Terms displayed below in bold type are EnviroFish variables.

Time Constraints

There are four levels of time constraint in EnviroFish. From the highest to lowest level, the time levels are analysis period, spawning season, spawning period, and a single day.

The analysis period is the highest level of time constraint. **Season Constraints** include a user-defined beginning year and ending year and the beginning and ending days of a user-defined fisheries season. As an example, suppose that the user-defined season starts on March 1st and ends on June 30th (displayed as **Season** 3/1 – 6/30 on **Season Constraints** input screen); the user-defined period is from 1980 to 1982 (displayed as **Period** 1980 **to** 1982 on the **Season Constraints** input screen); and the user-defined Spawning period is 8 days (displayed as **Days** 8 on the **Spawning Constraints** input screen). The EnviroFish program will evaluate rearing and spawning for each day from March 1st through June 30th for the years 1980, 1981, and 1982. In this example, a total of 122 daily calculations each for **Total Rearing**, **Restricted Rearing**, and **Spawning** will be performed for the three years in the period of record. The duration period evaluated for each calculation is one day for **Total Rearing** and **Restricted Rearing** and 8 days for **Spawning**.

Spawning

Unlike daily computations of rearing area, daily computations of spawning area evaluate changes in water surface elevation that occur during the spawning duration period, i.e., the daily value of spawning area evaluates conditions that occur on subsequent days. As an example, suppose that the user-defined season starts on March 1st and ends on June 30th (displayed

as 3/1 – 6/30 on **Season Constraints** input screen) and the user-defined spawning duration period is 8 days (displayed as **Days** 8 on the **Spawning Constraints** input screen). The Day 1 spawning calculation evaluates conditions that occur on Day 1 plus the subsequent seven days, which are March 1st through March 8th, the Day 2 calculation evaluates conditions that occur from March 2nd through March 9th, and the Day 122 calculation evaluates conditions that occur from June 30th through July 7th. As an additional example, suppose that the user-defined season starts on March 15th and ends on May 31st (displayed as 3/15 – 5/31 on **Season Constraints** input screen), and the user-defined spawning duration is 3 days (displayed as **Days** 3 on the **Spawning Constraints** input screen). The Day 1 spawning calculation evaluates conditions that occur on Day 1 plus the subsequent two days, which are March 15th through March 17th, the Day 2 calculation evaluates conditions that occur from March 16th through March 18th, and the Day 78 calculation evaluates conditions that occur from May 31st through June 2nd.

The parameters that are utilized for the daily spawning computations are elevation, area, **Season Constraints**, and **Spawning Constraints**. The user-defined **Spawning Constraints** are the minimum depth (**Min Depth**), maximum depth (**Max Depth**), spawning duration (**Days**), shallow nests (**Orphaned Nests**), and deep nests (**Deep Nests**). The **Min Depth** and **Max Depth** are identical to the corresponding **Rearing Constraints**, except that the selected constants may have different values. Shallow nests are those nests that are constructed near the water surface and deep nests are those nests that are constructed at greater depths. The effect of each of these variables on spawning is described in the following paragraphs.

The first day of any daily spawning calculation defines the maximum upper and lower boundaries for the daily calculation. The land surface area available during the first day of the spawning duration period is computed precisely as for **Restricted Rearing** described above. For a spawning duration of one day, the spawning daily calculations will follow an identical process as for **Restricted Rearing** daily calculations.

The effects of shallow nests and deep nests work in tandem and can only impact the daily spawning calculation for a spawning duration greater than one day. Shallow nests relate to the upper spawning boundary or “shallow” portion, and deep nests relate to the lower spawning boundary

or “deep” portion. Two user-defined settings each are possible for shallow nests. A checkmark symbol in the box before the words **Orphaned Nests** indicates that “abandoned” shallow nests are “allowed,” i.e., a reduction in the upper boundary elevation will only occur if the minimum water surface elevation in a spawning duration period is below the first day **Min Depth** elevation. An empty box before the words **Orphaned Nests** indicates that “abandoned” shallow nests are “not allowed,” i.e., a reduction in the upper boundary elevation will occur if the minimum water surface elevation in a spawning duration period is below the first day water surface elevation. A checkmark symbol in the box before the words **Deep Nests** indicates that “abandoned” deep nests are “allowed,” i.e., the lower boundary elevation is maintained at the first day **Max Depth** elevation. An empty box before the words **Deep Nests** indicates that “abandoned” deep nests are “not allowed,” i.e., an increase in the lower boundary elevation will occur if the maximum water surface elevation in a spawning duration period is above the first day water surface elevation.

There are four possible combinations of shallow nests and deep nests that can be selected for a period of record simulation:

1. Both shallow nests and deep nests are allowed.
2. Shallow nests are allowed and deep nests are not allowed.
3. Shallow nests are not allowed and deep nests are allowed.
4. Neither shallow nests nor deep nests are allowed.

The least restrictive of the four combinations occurs when both shallow nests and deep nests are allowed. For each spawning period calculation, two cases are possible:

a. The first day **Min Depth** elevation is less than or equal to the minimum water surface elevation for every subsequent day of the spawning period.
b. The first day **Min Depth** elevation is greater than the minimum water surface elevation for a subsequent day of the spawning period.

If case (a) governs, the upper boundary is equal to the first day **Min Depth** elevation and the lower boundary is equal to the first day **Max Depth** elevation. The resultant spawning period value is the land surface area bounded by the upper boundary and the lower boundary. If case (b) governs, the upper boundary is the minimum water surface elevation during the spawning period and the lower boundary is equal to the first

day **Max Depth** elevation. The resultant spawning period value is the land surface area bounded by the upper boundary and the lower boundary.

Next, consider combination (2), in which shallow nests are allowed and deep nests are not allowed. The upper boundary is determined by following the process for combination (1). The lower boundary is determined by subtracting the **Max Depth** spawning constraint value from the maximum water surface elevation during the spawning duration period. The resultant spawning period value is equal to the land surface area bounded by the upper boundary and the lower boundary.

Consider combination (3), in which shallow nests are not allowed and deep nests are allowed. The upper boundary is determined by subtracting the **Min Depth** spawning constraint value from the minimum water surface elevation during the spawning period. The lower boundary is the first day **Max Depth** elevation. The resultant spawning period value is the land surface area bounded by the upper boundary and the lower boundary.

Finally, consider combination (4), in which neither shallow nests nor deep nests are allowed. This combination is the most restrictive of the four combinations. The upper boundary is determined by subtracting the **Min Depth** spawning constraint value from the minimum water surface elevation during the spawning period. The lower boundary is determined by subtracting the **Max Depth** spawning constraint value from the maximum water surface elevation during the spawning period. The resultant spawning period value is the land surface area bounded by the upper boundary and the lower boundary.

For each of the possible four combinations in the EnviroFish program, the minimum area value for any day cannot be less than zero. Any daily evaluation of spawning that computes an upper boundary elevation equal to or less than the lower boundary elevation results in a total area value of zero.

Rearing

Daily computations of rearing area evaluate only the water surface elevation for one day, i.e., the daily value evaluates neither water surface elevations that have occurred on previous days nor on subsequent days. The Day 1 computation uses the water surface elevation on Day 1 only; the Day 2 computation uses the water surface elevation on Day 2 only, etc. The

parameters used to compute the rearing computations for each day are elevation, area, **Season Constraints**, and **Rearing Constraints**. The **Rearing Constraints** are the minimum depth (**Min Depth**), and maximum depth (**Max Depth**). **Min Depth** and **Max Depth** are user-defined numeric values that are constant for the period of record selected. The parameter **Total Rearing** is computed for each day in the period of record and is simply the amount of land surface area at and below the water surface elevation and is the maximum potential area available to rearing fishes. **Restricted Rearing** is computed for each day in the period of record and is the amount of land surface area that is bounded by the user-defined **Rearing Constraints** related to the daily water surface elevation. The **Restricted Rearing** value for each day in the period of record is that quantity of area that has an upper boundary at the **Min Depth** below the water surface elevation and has a lower boundary at the **Max Depth** below the water surface elevation. As an example, suppose that the water surface elevation on Day 25 is 100 feet, the **Min Depth** is 1 foot, and the **Max Depth** is 10 feet. The **Restricted Rearing** value for Day 25 is the amount of land surface area that has an upper boundary of 99 feet and a lower boundary of 90 feet.

Appendix D: Hydrologic Plan

A hydrologic plan is a prerequisite for a successful application of Enviro Fish. The planner of an EnviroFish analysis needs a general understanding of how hydrologic methods support the application of EnviroFish. This chapter is a brief introduction to some of the hydrologic issues that may arise in planning an EnviroFish analysis and includes the following four topics:

1. Site hydrologic classification
2. Water control components and passive processes
3. Comparison of HEC-HMS and HEC-RAS
4. Assembling the hydrologic plan

Site Hydrologic Classification

The planner of an EnviroFish analysis should identify the characteristics of the site that dominate how hydrologic data can be used and how hydrologic modeling can be performed. The simple site classification system described below can serve as an initial planning aid, although it does not include all possible aspects of EnviroFish applications. The classification system identifies the operational and tailwater characteristics of the site.

Operational controls permit people to change flows and water levels within the site. Examples of controls are gated culverts, flashboard weirs with changeable crest elevations, flood control pumps, and water supply pumps. Controls should be distinguished from project alternatives that do change water levels, but have only a fixed operation. For example, an alternative to install a low earthen dam with a fixed spillway would change water levels at the site, but the water levels would be entirely determined by flows, topography, and the fixed spillway characteristics. Under both existing conditions and the alternative, such a site is uncontrolled.

Tailwater elevation is the water surface elevation immediately downstream of the EnviroFish analysis site. Tailwater elevation is important, because it controls the site water surface elevation required to force headwater flow through the site. The tailwater characteristics are classified as either dependent or independent. If the elevation of tailwater depends only on

the amount of flow through the site, then the tailwater is dependent. Under dependent tailwater conditions, the greater the flow through the site, the higher the water surface elevation at the site, and the fixed relationship between flow and elevation can be listed in a single rating table or plotted in a single rating curve. Alternatively, if the elevation of tailwater can be affected by any other cause than the flow passing through the site, then the tailwater is independent. Under independent tailwater conditions, it is not possible to develop a single rating table or a single rating curve that accurately describes the relationship between flow through the site and the water surface elevation at the site for all possible conditions downstream of the site.

Based on the possible combinations of control and tailwater, there are four categories in the classification system:

1. Uncontrolled, dependent tailwater
2. Uncontrolled, independent tailwater
3. Controlled, dependent tailwater
4. Controlled, independent tailwater

Six examples of site hydrologic classification are provided below. The first two examples concern the establishment of forest in a floodplain. The remaining examples concern the installation of a low dam and shallow reservoir.

Example 1. Uncontrolled, dependent tailwater (forest)

An example of an uncontrolled, dependent tailwater site is shown in plan and section views in Figure D-1. The plan view shows an unforested stream and floodplain under existing conditions, with the project alternative to be the establishment of a small patch of forest, shown as a green hatched rectangle. There is no downstream tributary to affect flowlines at the site. No controllable dam is downstream of the site. The elevation of floodwater at the site is solely a function of the flow through the site, therefore, the site has dependent tailwater. No on-site controllable structures are included with the establishment of the forest; therefore, the site is uncontrolled.

Continuing with the example of Figure D-1, the patch of forest is considered small enough to have a negligible effect on flood flows and elevations through the stream reach. If suitable gage data is available for

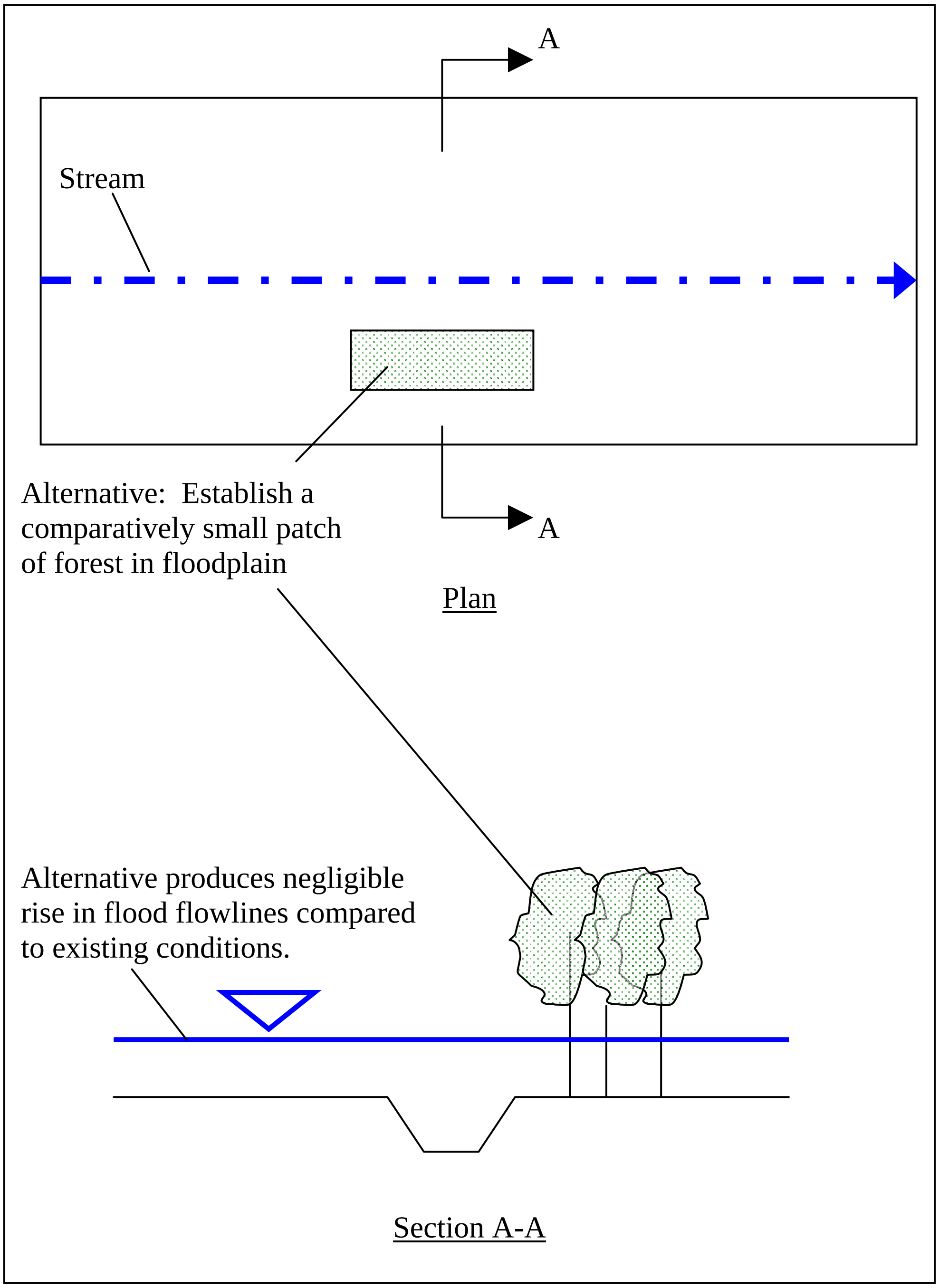

Figure D1. Uncontrolled Site with Dependent Tailwater, Alternative – Establish Forest.

input to EnviroFish, that data can be used for both existing conditions and for the alternative. Or, if gage data is not available, the hydrologic and hydraulic analyses sufficient to describe existing conditions should also describe the alternative satisfactorily. However, if the patch of forest is large enough to significantly increase the resistance to flood flows, then modeling is required to distinguish between existing conditions and the

alternative. For example, even if gage data were available to describe existing conditions without modeling, hydrologic and hydraulic models would be required to quantify the higher water surface elevations that would be caused by the increased flow resistance of the forest.

Example 2. Uncontrolled, independent tailwater (forest)

An example of an uncontrolled, independent tailwater site is shown in plan and section views in Figure D-2. The plan view shows an unforested stream and floodplain under existing conditions, with the project alternative to be the establishment of a small patch of forest, shown as a green hatched rectangle. Just downstream of the site, the stream joins a much larger river. Although no downstream controllable dam is close enough to affect flowlines at the site, the elevation of floodwater at the site is not solely a function of the flow through the site, because many combinations of flow in the stream and in the river upstream of the confluence could produce the same water surface elevation at the site. Therefore, the site has independent tailwater. The possibility of different flow conditions causing the same water surface elevation at the site is shown in Figure D-3. In Figure D-3 the stream is shown in profile and the river is shown as a trapezoidal section. The solid blue line sloping downward to the right represents a headwater flood flowline for the stream at a time when the river is low. The flowline is parallel to the top of stream bank and the short, red, double-headed arrows indicate the depth of flooding above the stream bank and floodplain. The twin trees shown in hatched green foliage represent the location of the site. Alternatively, the dashed blue line represents the flowline for the stream at a time when the river is high. At the far left of the figure, the dashed blue line is below the top of the stream bank and is falling to the right, indicating that the stream flow is not great enough to flood the stream floodplain. However, the river flow from upstream of the confluence is great enough to cause flooding in the floodplain of the river. This river floodwater backs into the stream and produces a level flowline with respect to the stream profile. The river flooding is high enough that backwater flooding occurs in the stream floodplain at the project site. The backwater flooding is indicated by the green double-headed arrows. Within the project site there is point, "D," at which the depth of flooding due to headwater and backwater are the same. No on-site controllable structures are included with the establishment of the forest; therefore, the site is uncontrolled.

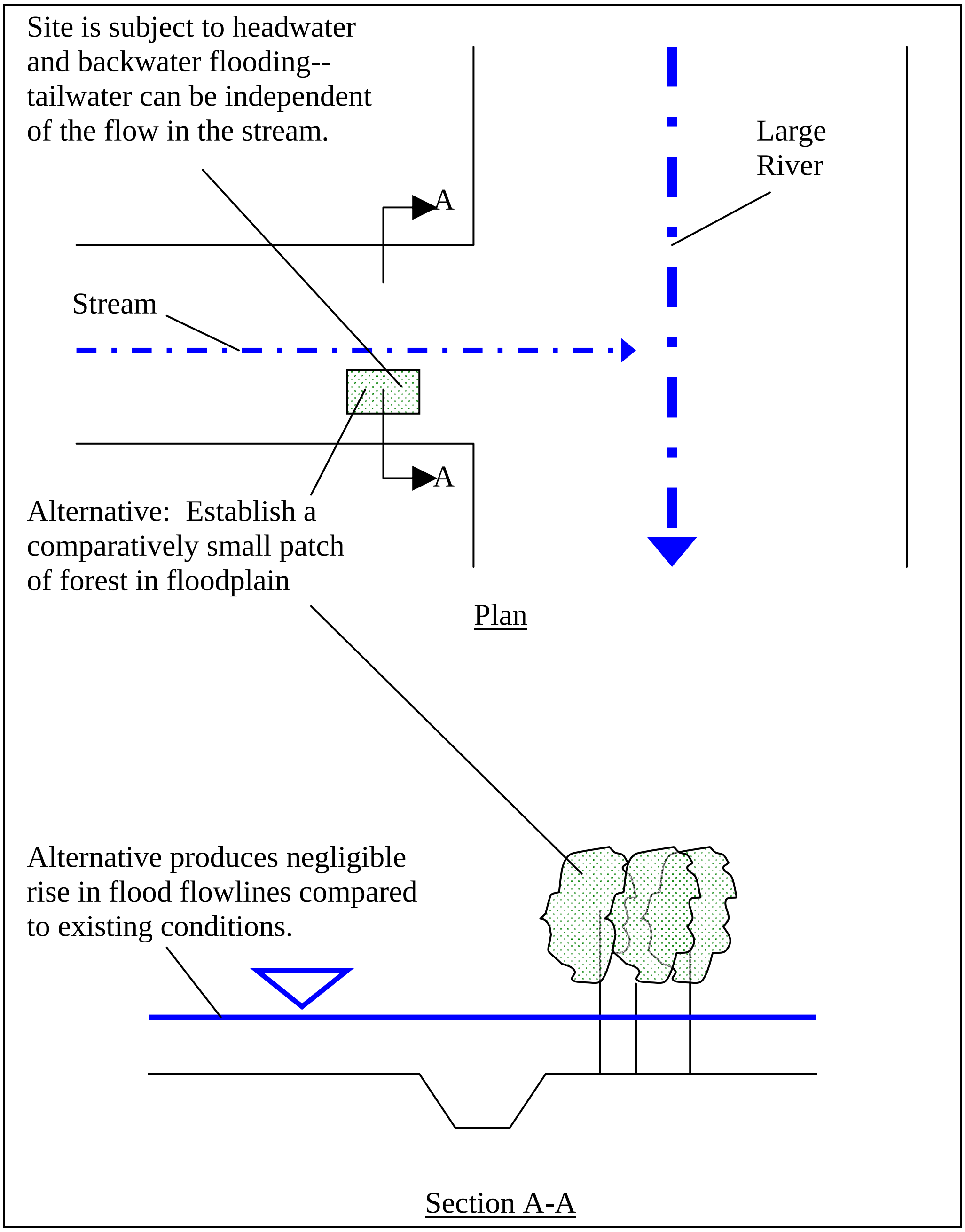

Figure D2. Uncontrolled Site with Independent Tailwater, Alternative – Establish Forest.

Continuing with Example 2, the data and modeling considerations for the patch of forest are the same as for Example 1, except that the gage data used should reflect both the behavior of the stream and the river. For example, a gage fortuitously located at the site would reflect the combined effects of headwater and backwater flooding. If no gage is located at the site, then a gage farther upstream on the stream and another gage on the river together might furnish usable data if a satisfactory method is available to transform the elevations to values appropriate for the site.

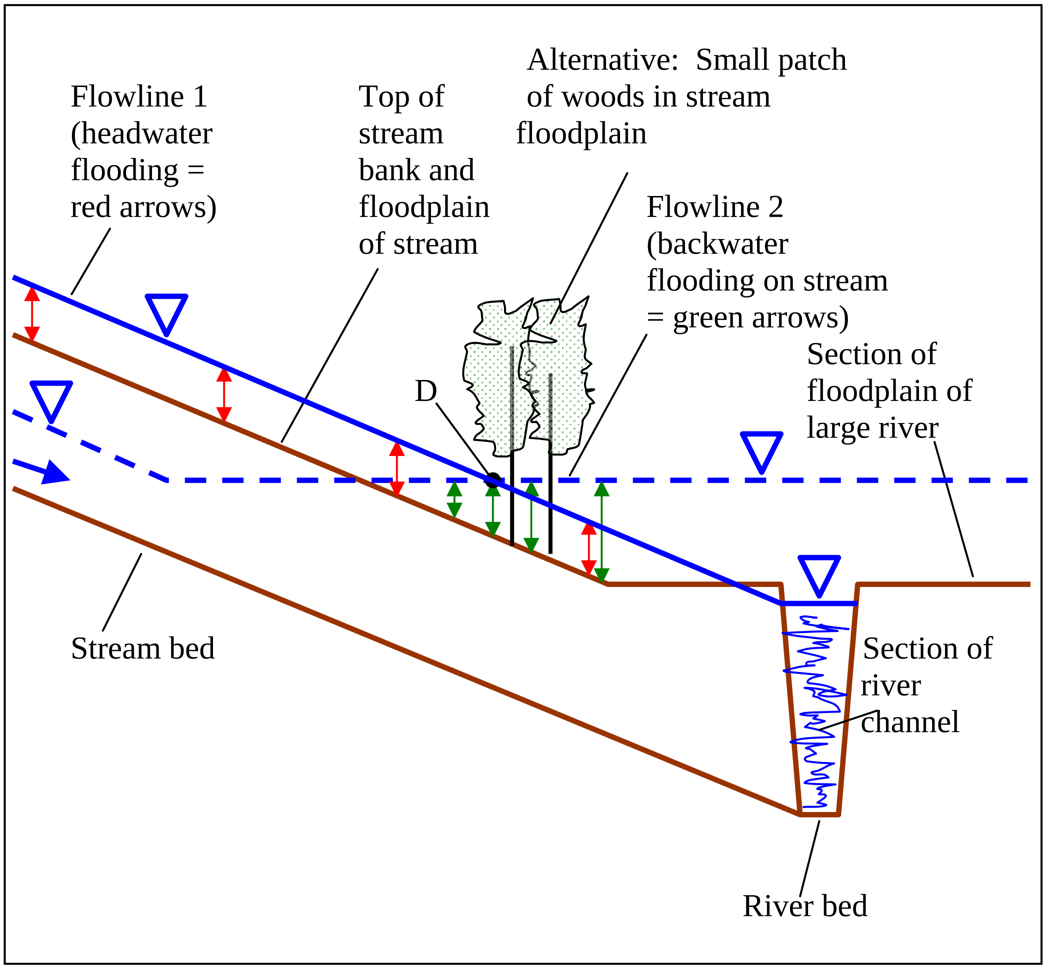

Figure D3. Uncontrolled Site with Independent Backwater, Profile of Headwater and Backwater Flooding, Alternative – Establish Forest.

Example 3. Uncontrolled, dependent tailwater (dam)

A second example of an uncontrolled, dependent tailwater site is shown in plan and section views in Figure D-4. The plan view shows an unforested stream and floodplain under existing conditions, with the project alternative to be the installation of a low dam and shallow reservoir. No tributary joins the stream close downstream of the site. No controllable dam is close downstream of the site. The elevation of floodwater at the site is solely a function of the flow through the site; therefore, the site has dependent tailwater. The dam has a fixed spillway and no other controllable features are included; therefore, the site is uncontrolled.

Continuing with Example 3, although the dam is uncontrolled, it does change water levels at the site. If suitable gage data is available for input to EnviroFish, that data can be used for existing conditions, but not for the alternative, which requires modeling.

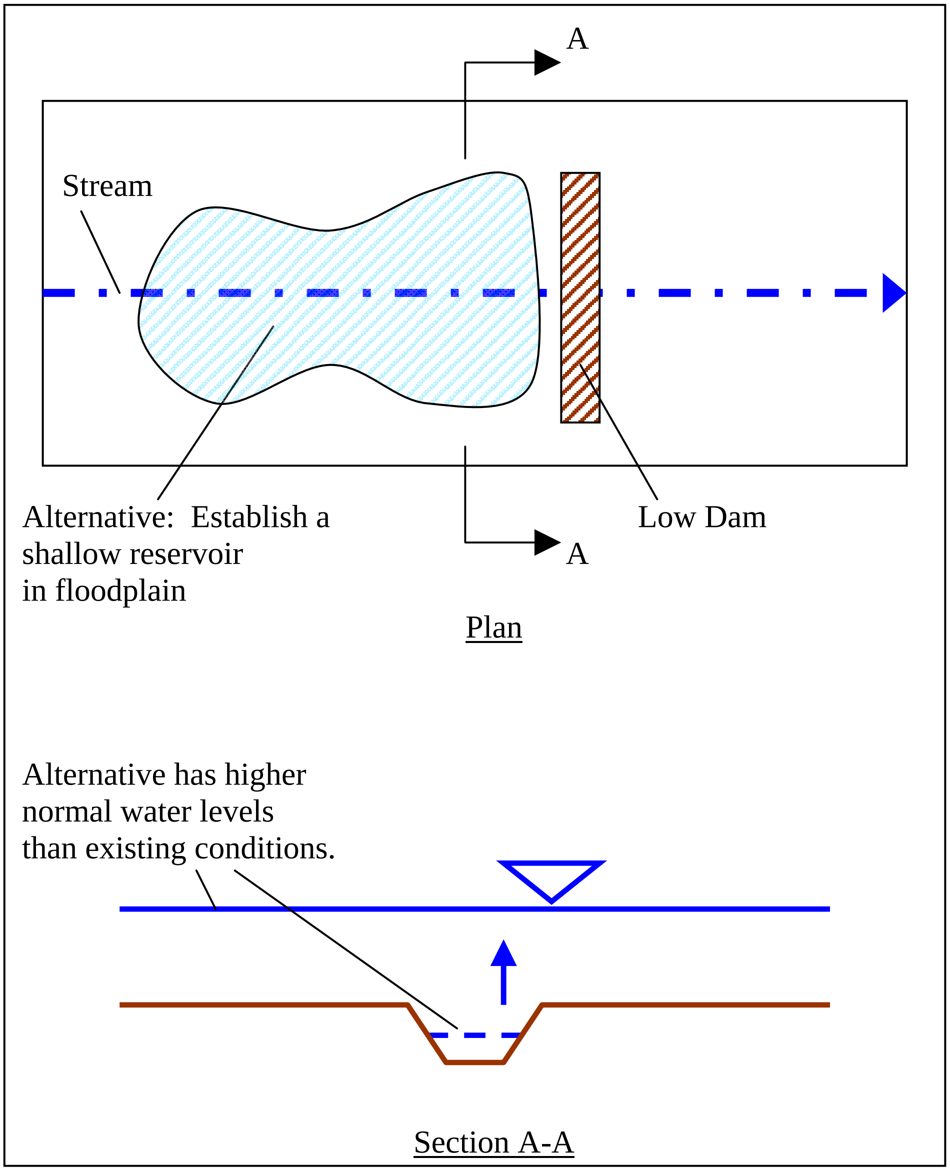

Figure D4. Uncontrolled Site with Dependent Tailwater, Alternative – Install Dam.

Example 4. Uncontrolled, independent tailwater (dam)

A second example of an uncontrolled, independent tailwater site is shown in plan and section views in Figure D-5. The plan view shows an unforested stream and floodplain under existing conditions, with the project alternative to be the installation of a low dam and shallow reservoir. Just downstream of the site, the stream joins a much larger river. For the same reasons described in Example 2, this site also has independent tailwater. The dam has a fixed spillway and no other controllable features are included; therefore, the site is uncontrolled. Although available gage data may be satisfactory as input to EnviroFish, the low dam must be modeled.

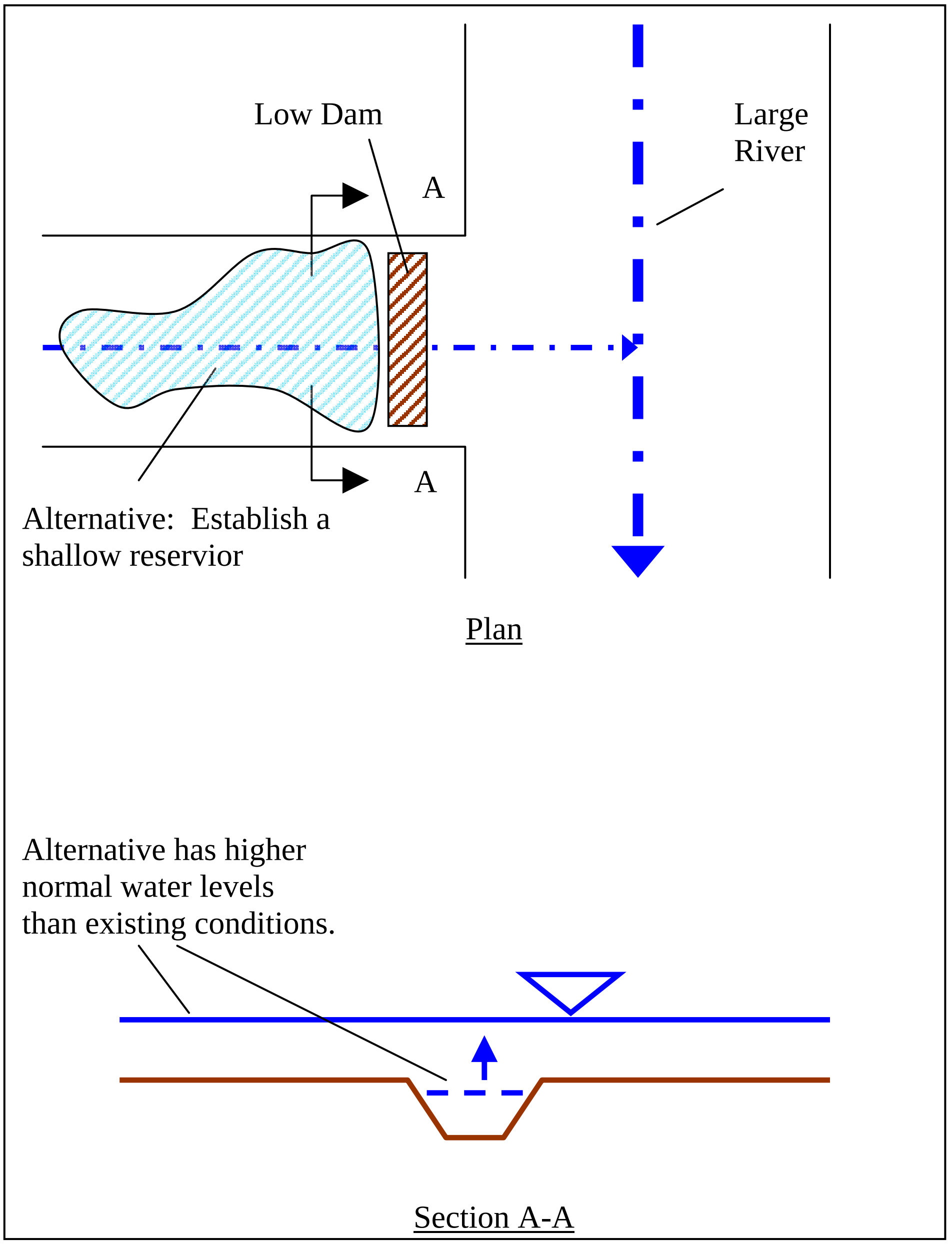

Figure D5. Uncontrolled Site with Independent Tailwater, Alternative – Install Dam.

Example 5. Controlled, dependent tailwater (dam)

If a dam with controllable spillways were substituted for the dam featured in Example 3, then the alternative would be controlled, with dependent tailwater. Water supply pumps would also provide control. Modeling is required to characterize this alternative, even if gage data is available to characterize existing conditions.

Example 6. Controlled, independent tailwater (dam)

If a dam with controllable spillways were substituted for the dam featured in Example 4, then the alternative would be controlled, with independent tailwater. As in Example 5, water supply pumps would also provide control, and modeling is required to characterize this alternative, even if gage data is available to characterize existing conditions.

Water Control Components and Passive Processes

The effect of project water control components and passive processes should be reflected in an EnviroFish analysis. The hydrologic plan should identify which controls and passive processes will be accounted for, and which software capable of modeling the site realistically has been selected for modeling. An example list of six control components and passive processes is provided below.

The first four items are control components and the last two items are passive processes:

1. gated culverts
2. flood control pumps
3. flashboard weirs
4. pumped wells
5. levee under seepage
6. seepage wells

Gated culverts (control component)

Although the purpose of a levee is to protect the land side from river flooding, a levee also obstructs the normal flow of runoff from the land side to the river. Gated culverts installed through levees allow land side runoff to flow into the river. The gate is normally kept open while the river is low. If the river is high, the gate is shut to prevent river water from flowing backward through the culvert and flooding the land side of the levee.

The operation cycle of a gated culvert through a levee is illustrated in Figures D-6, D-7, and D-8. In this example, the gate is operated solely for flood protection on the land side of the levee. Figure D-6, Step 1 shows the gated culvert in its normal condition, with the river low and the gate open.

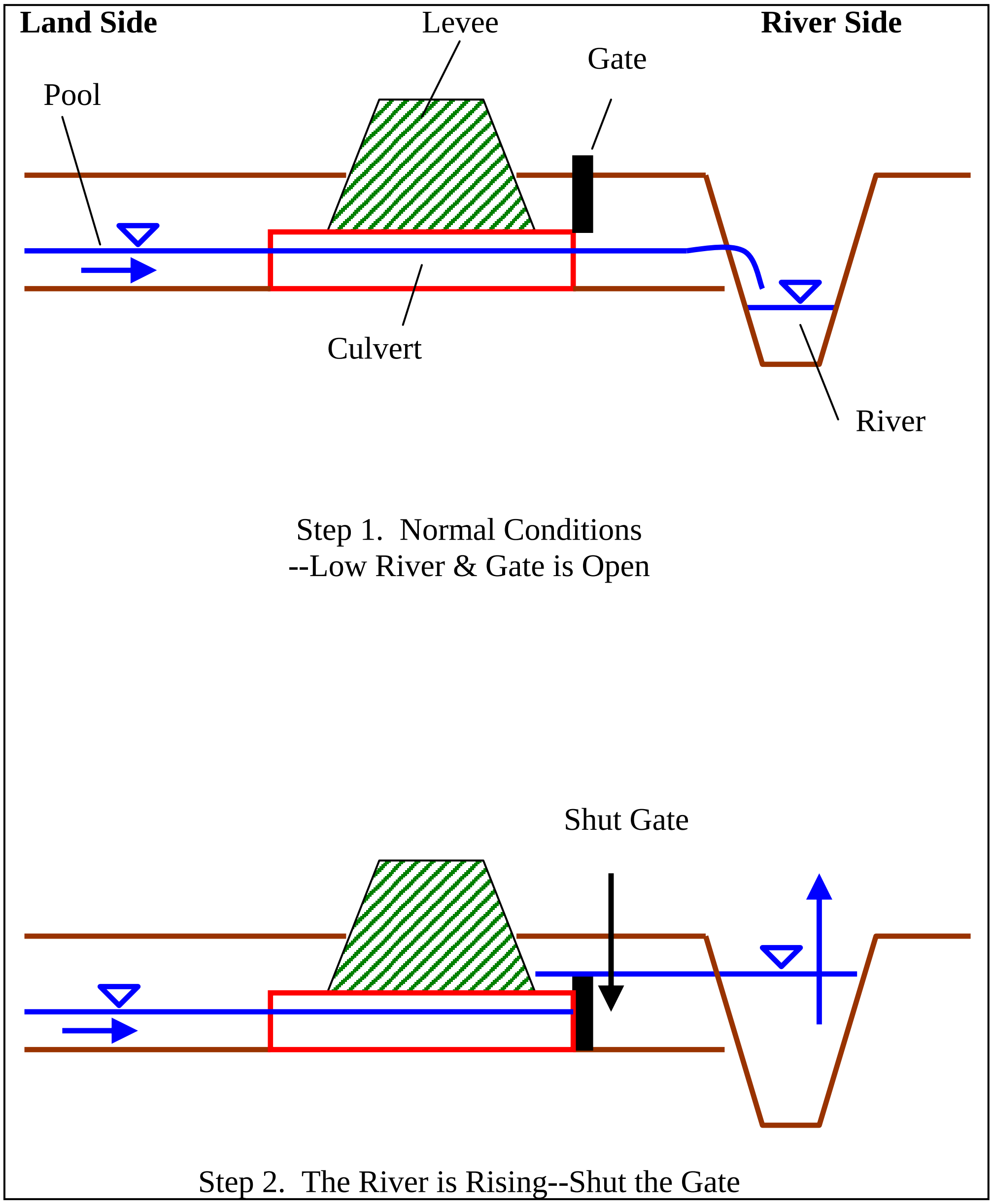

Figure D6. Gate Operation Cycle at Culvert Through Levee (Steps 1 and 2).

Runoff does not accumulate on the land side of the levee, but instead flows freely though the culvert and flows into the river. Step 2 shows the river rising. The gate is shut to prevent the river water from flowing backward through the culvert. Runoff has not yet had time to accumulate on the land side. In Figure D-7, Step 3, the river has risen higher. Runoff has had time to accumulate on the land side of the levee and the pool is also rising. In some situations, levee underseepage also contributes to the accumulation of water on the land side. The pool level on the land side is not as high as the river level, and the gate remains shut, since — if the gate were opened — river water would flow into the land side area and increase the flooding

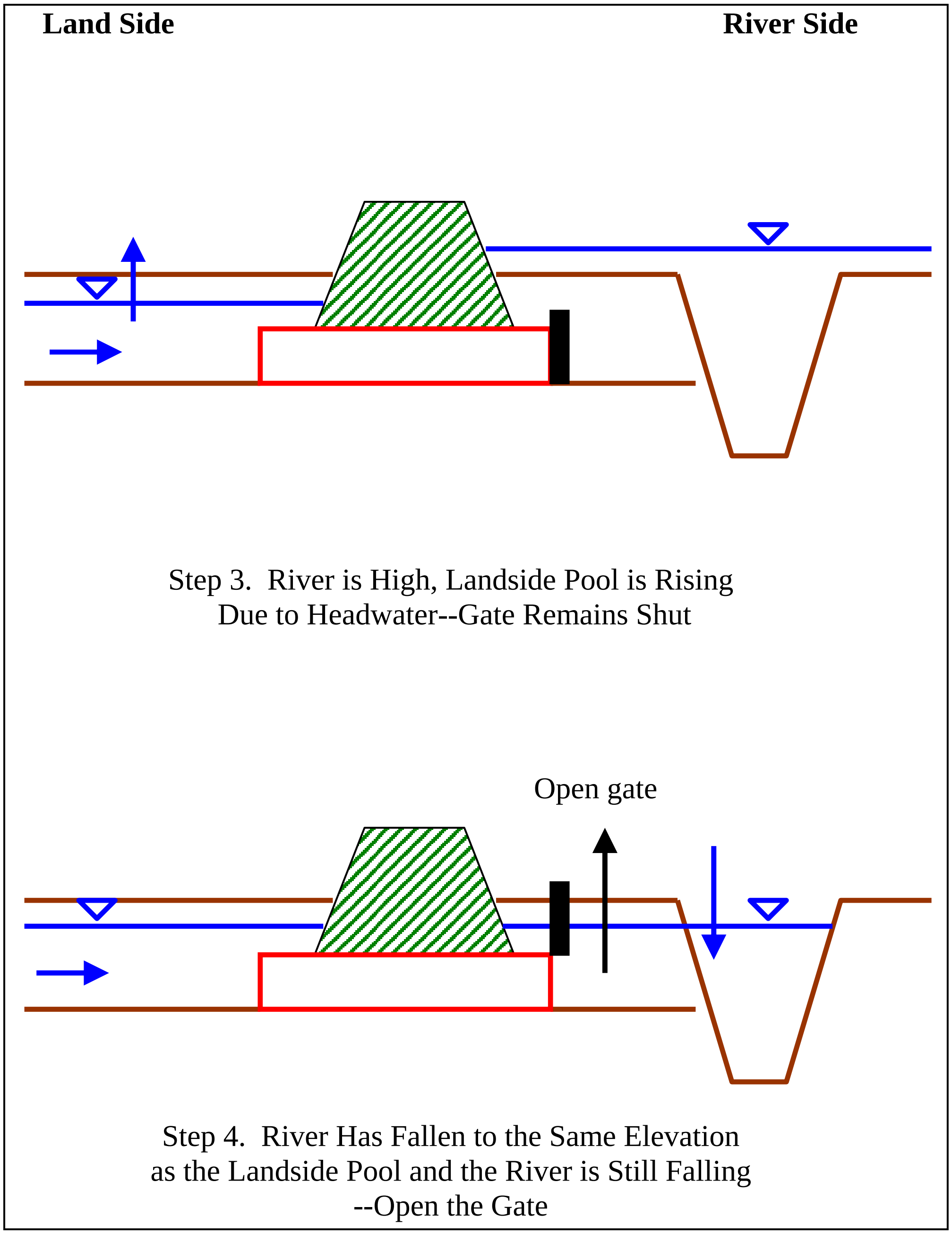

Figure D7. Gate Operation Cycle at Culvert Through Levee (Steps 3 and 4).

there. In Step 4, the river has fallen to the same elevation as the accumulated runoff on the land side, and the river continues to fall. The gate is opened, since the falling river allows the pool on the land side of the levee to fall also. In Figure D-8, Step 5, the river continues to fall. The gate remains open and the pool falls also. In Step 6, normal conditions have resumed. The river is low, the gate is open, and land side runoff flows into the river.

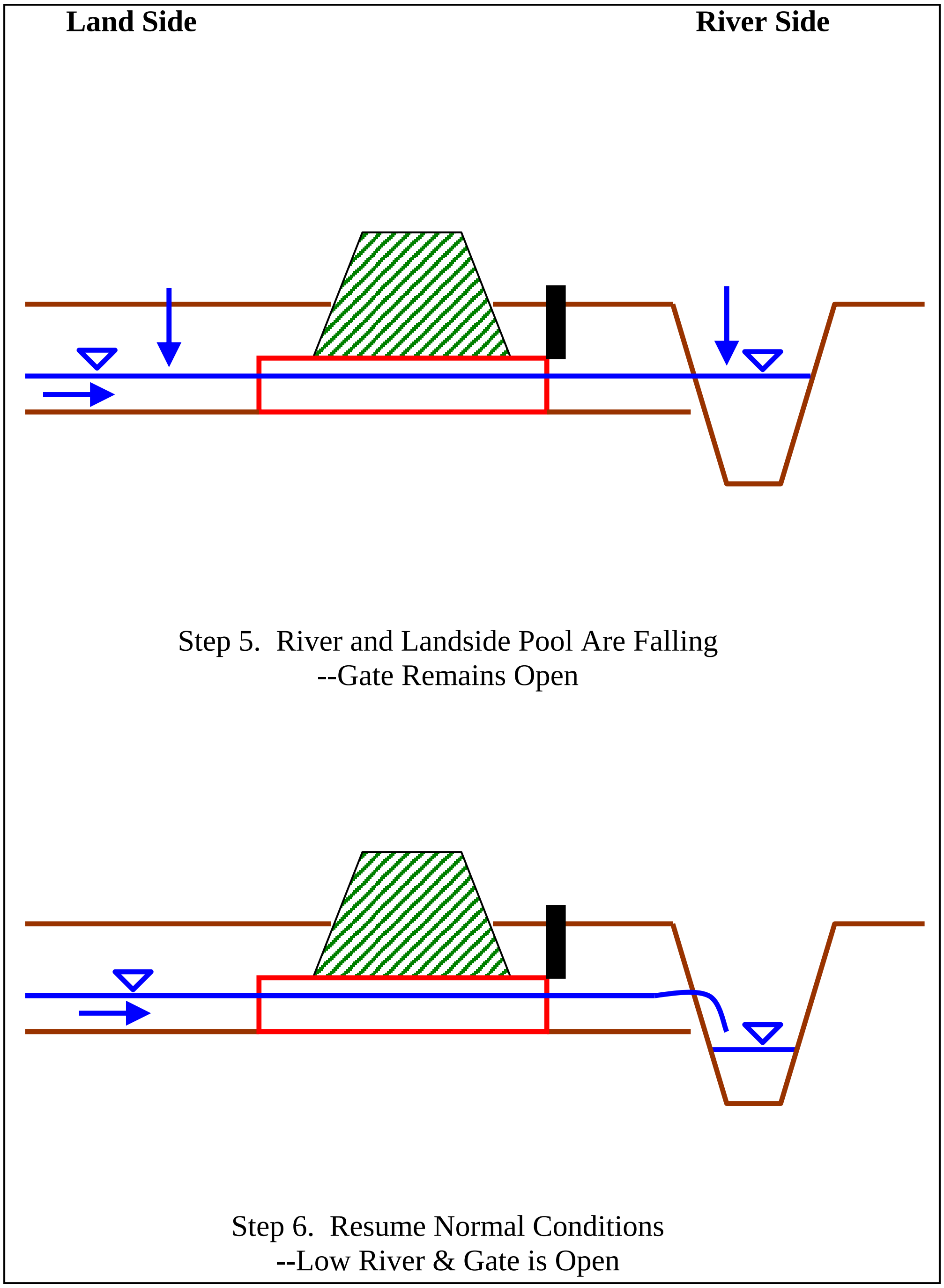

Figure D8. Gate Operation Cycle at Culvert Through Levee (Steps 5 and 6).

The operation cycle of gated culverts for flood control projects can be continuously simulated using the HEC-RAS software in the unsteady flow mode. The more difficult HEC-RAS task is to impose seasonal rules for gate operation, including the holding of land side pools against a low river.

Closed culvert gates are subjected to heavy forces if water levels are not equal on either side of the levee. As shown in Figure D-9, gates are usually installed on the river side end of the culvert. The high water level in the river shown in Figure D-9 exerts a large force against the shut gate. The shallow ponded water on the land side of the gate also exerts force in the opposite direction against the gate, but the net force from the river side is considerable, nevertheless. The massive concrete at the end of the culvert is able to support the net pushing force exerted by the gate. The gate presses against a heavy, smooth iron surface embedded in the culvert concrete. The greater the force on the gate, the tighter the seal.

If a project alternative would require a gated culvert to hold a pool for habitat on the land side of the levee against a lower river level, a careful structural check should be performed. As shown in Figure D-10, the water force on the shut gate from the land side is greater than the force from the river side, because the river level is lower than the pool level. The net force on the gate tends to push the gate away from the end of the culvert. There are heavy iron supports that hold the gate against the iron seal, but there is a limit to the tension the supports can withstand. Also, the greater the net force from the land side, the poorer the seal and the greater the tendency for leakage. Not only should the specifications of the gate be checked, but other structural and geotechnical design checks of the culvert and foundation may also be required. In the case of a new gated culvert installation, the designers should be advised at the beginning of the design process that the structure is to hold a land side pool against a low river.

Flood control pumps (control component)

Flood control pumps control the level of the pool that the water is pumped from, and operate only if gravity outflow is not possible. A typical application of flood control pumps is to protect the land side of a levee, as shown in Figure D-11. Sources of inflow to the land side pool may include direct rainfall onto the pool, runoff from upstream, and levee under seepage.

Flood control pumps can be controlled seasonally to maintain a pool elevation within desired limits. The pumps operate in an on/off cycle. If the pool elevation rises to an elevation referred to as "start pump" elevation, the pump is turned on. Pumping continues until the pool falls to an elevation referred to as "stop pump" elevation.

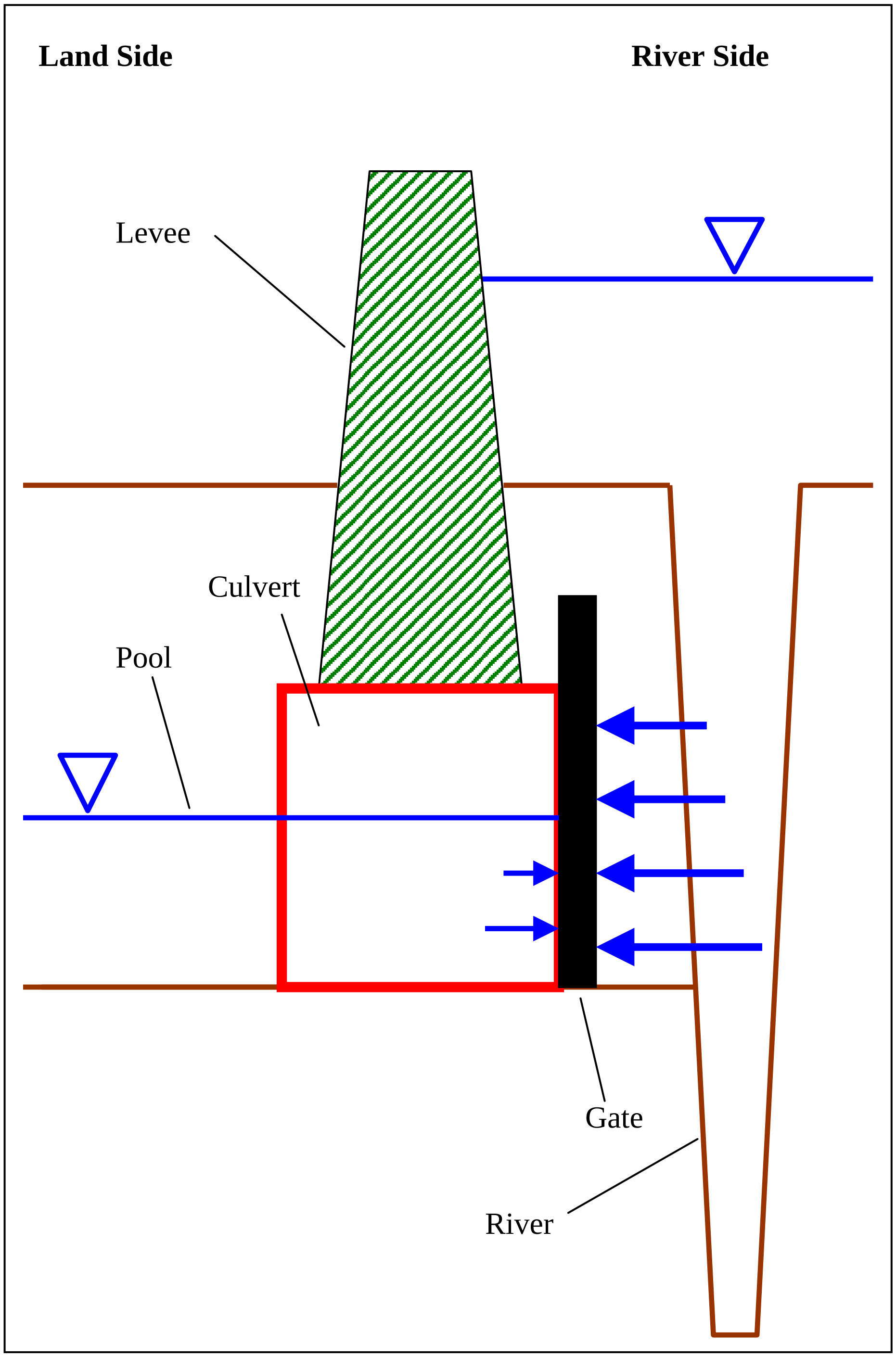

Figure D9. Forces on Shut Culvert Gate Due to High River.

Flashboard weir (control component)

A flashboard weir is a small spillway installed in a low earthen dam. The pool held upstream of the dam and flashboard weir is shallow. The crest elevation of a flashboard weir can be adjusted for seasonal control of water levels.

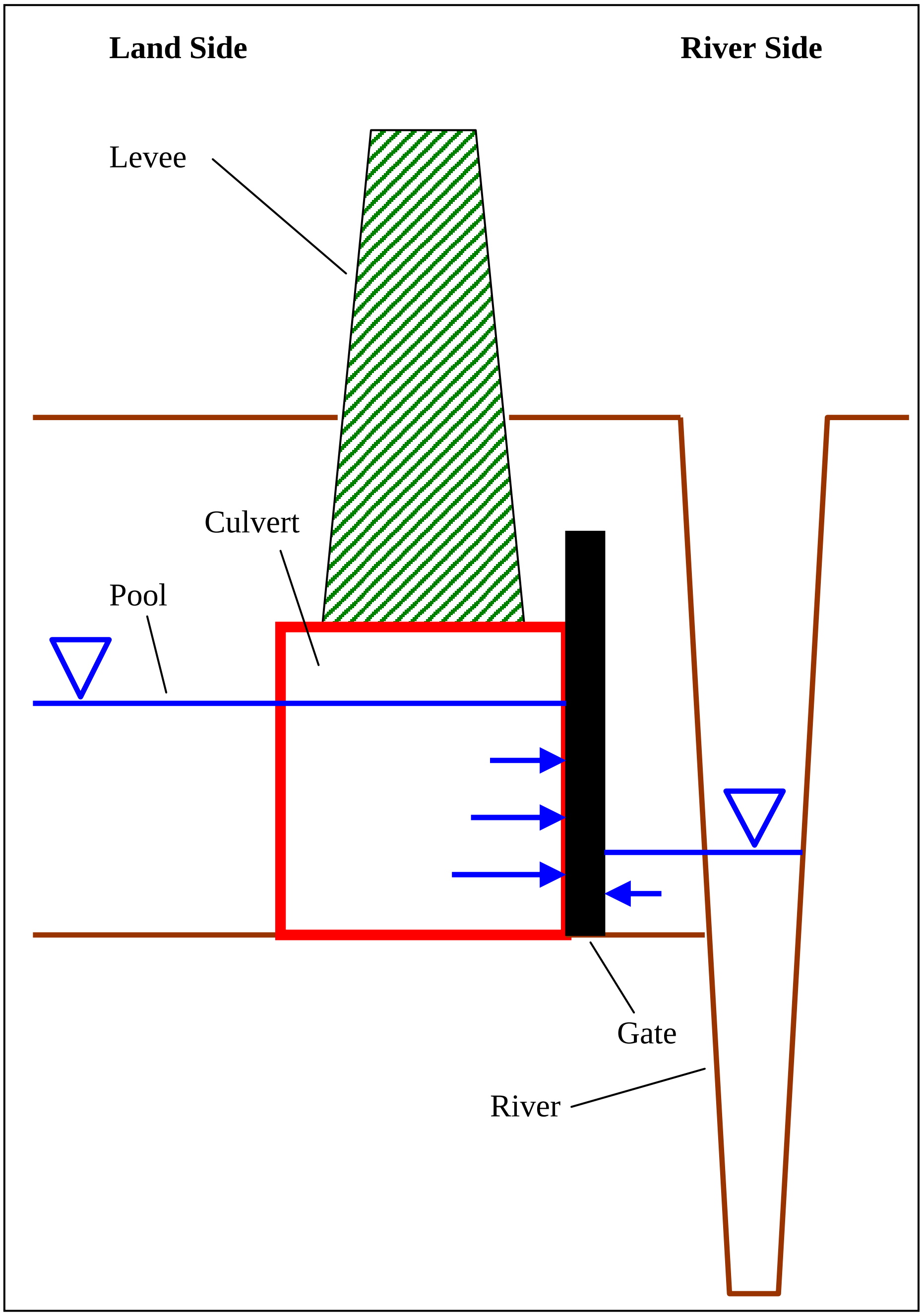

Figure D10. Forces on Shut Culvert Gate Due to High Land Side Pool.

In the simplest design, shown in Figure D-12, timber flashboards are stacked on top of each other until the desired crest elevation is achieved. Any excess water in the reservoir spills over the crest. If, for example, the five stacked flashboards shown in Figure D-12 were used to hold high water levels during the non-growing season, then the top two flashboards could be removed to set lower water levels for the growing season. If the pool needs to be lowered as much as possible for maintenance, all five flashboards could be removed.

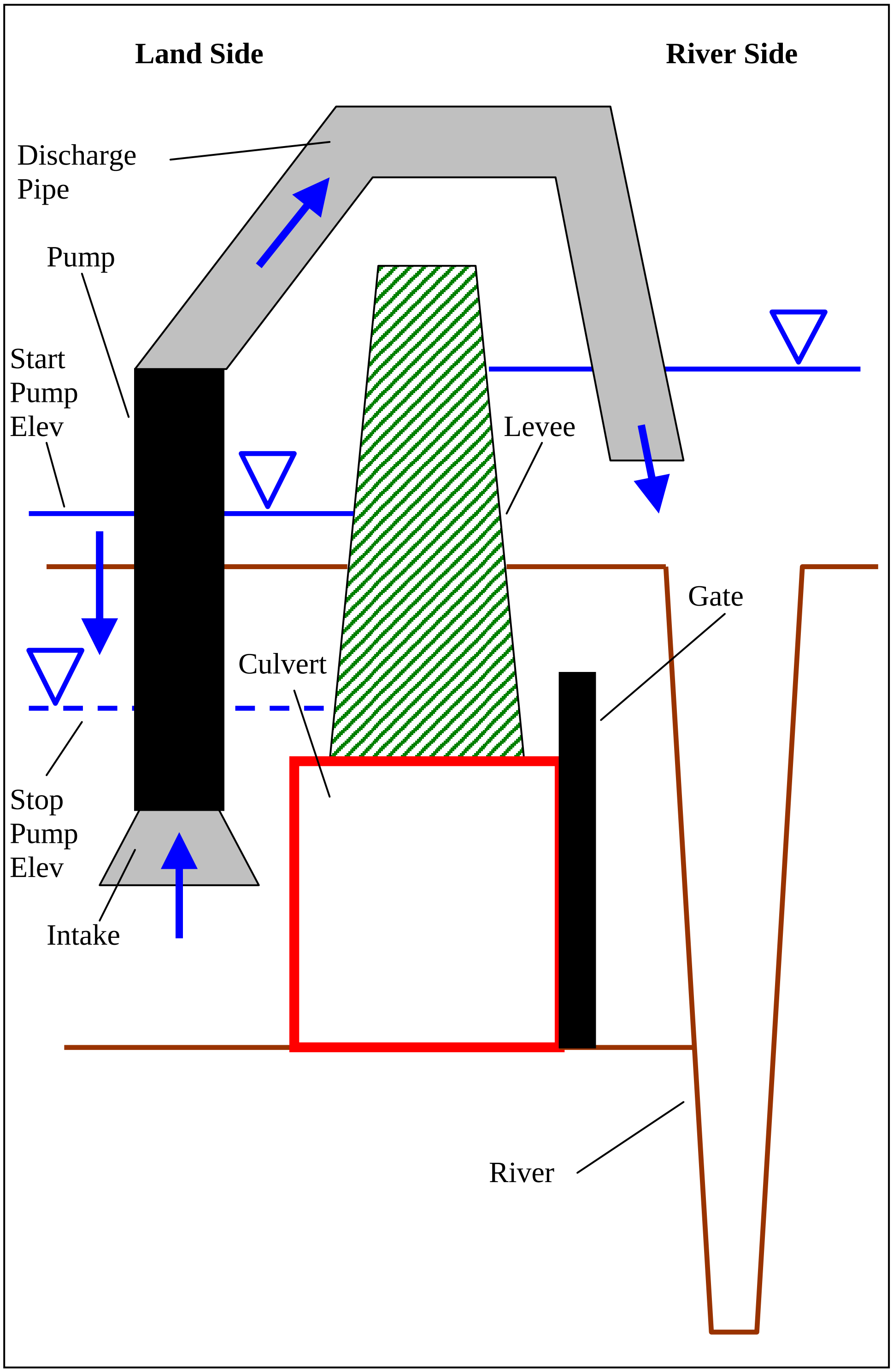

Figure D11. Flood Control Pumping Due to High River.

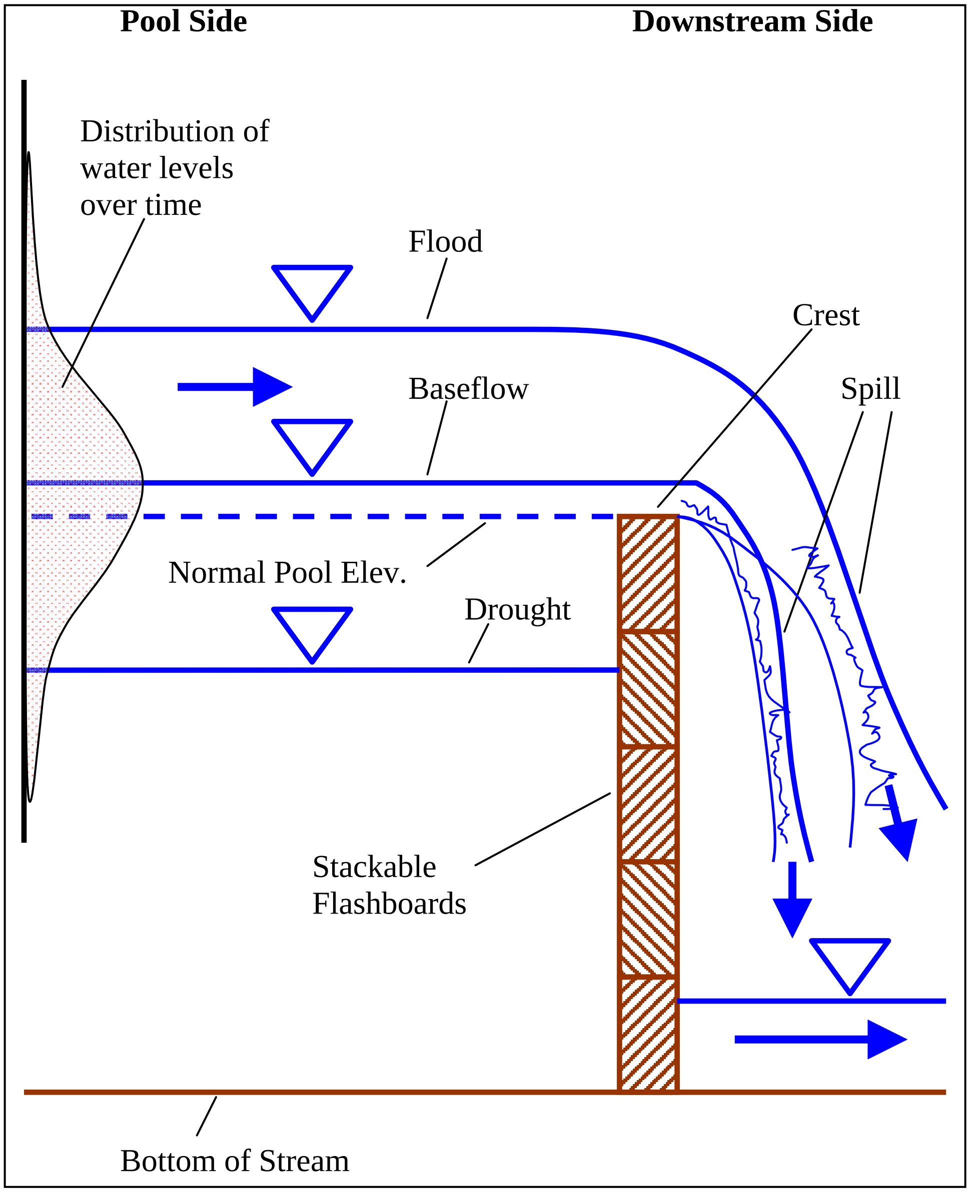

Figure D12. Flashboard Weir.

In general, the water surface elevation of the pool upstream of the flashboards ranges both above and below the normal pool elevation set by the crest of the flashboards. This range of water levels is illustrated by the bell curve to the left of the figure. Pool elevation occasionally rises to flood levels and occasionally falls below the flashboard crest due to drought; however, most of the time the pool level is near normal pool elevation, provided there is enough drainage area. The shorter the flashboard weir, the higher the pool will rise above normal pool elevation to pass flood-waters downstream, if tailwater level does not control. Continuous simulation can be used to estimate how high the pool will rise during floods of various magnitudes.

Pumped wells (control component)

Pumped wells control the level of the pool that the water is pumped into; they operate if the supply of direct rainfall and runoff to the pool is not sufficient. Pumped wells are a source of water that can be controlled seasonally to maintain a pool elevation within desired limits. Controlled pumped wells operate in an on/off cycle. As shown in Figure D-13, if the pool elevation drops to an elevation referred to as "start pump" elevation, the well pump is turned on. Pumping continues until the pool rises to an elevation referred to as "stop pump" elevation.

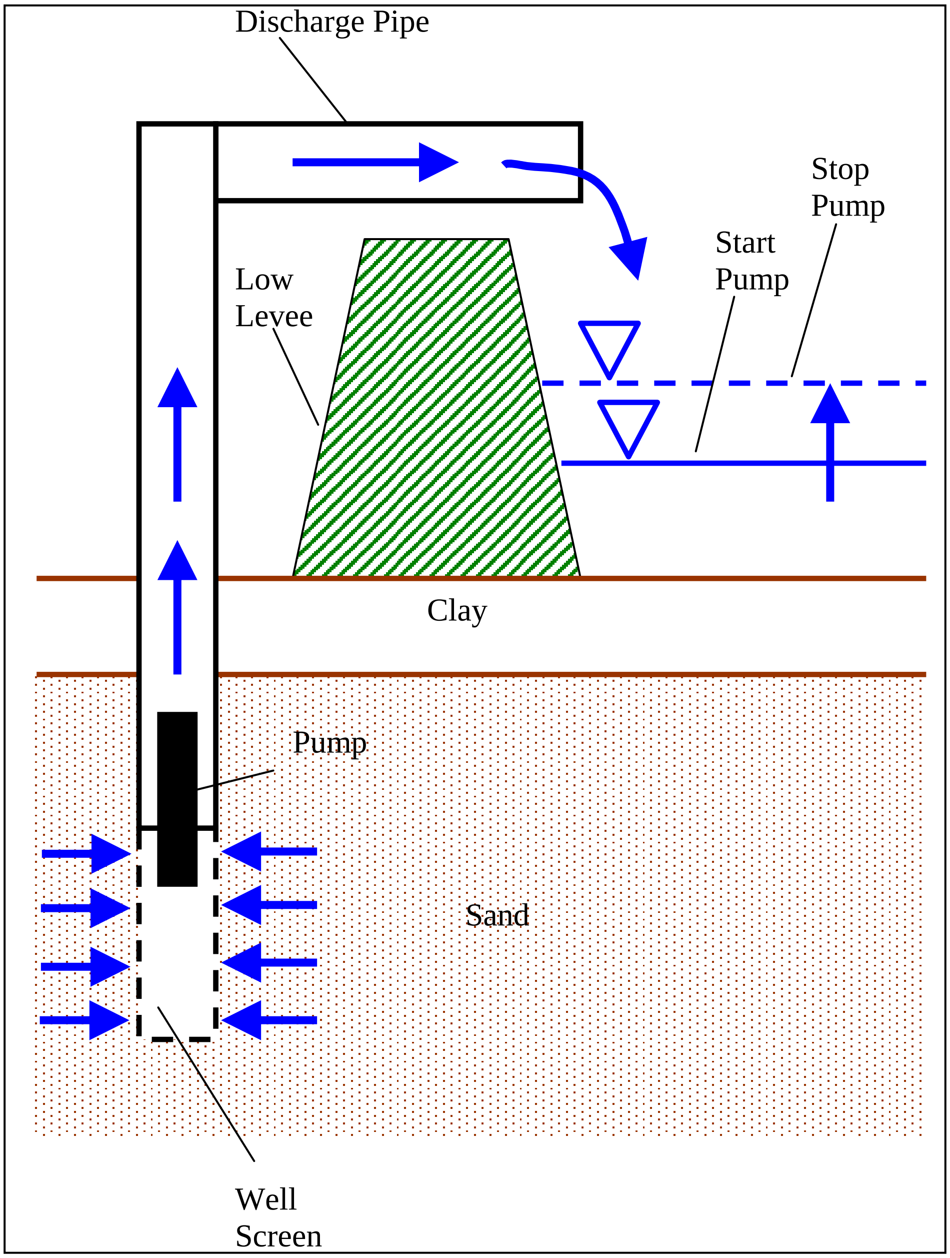

Figure D13. Pumped Well.

Levee underseepage (passive process)

Levee underseepage may be a source of water to an EnviroFish analysis site. As shown in Figure D-14, a high river level may drive water deep beneath a levee and cause seepage water to emerge on the land side of the levee and accumulate.

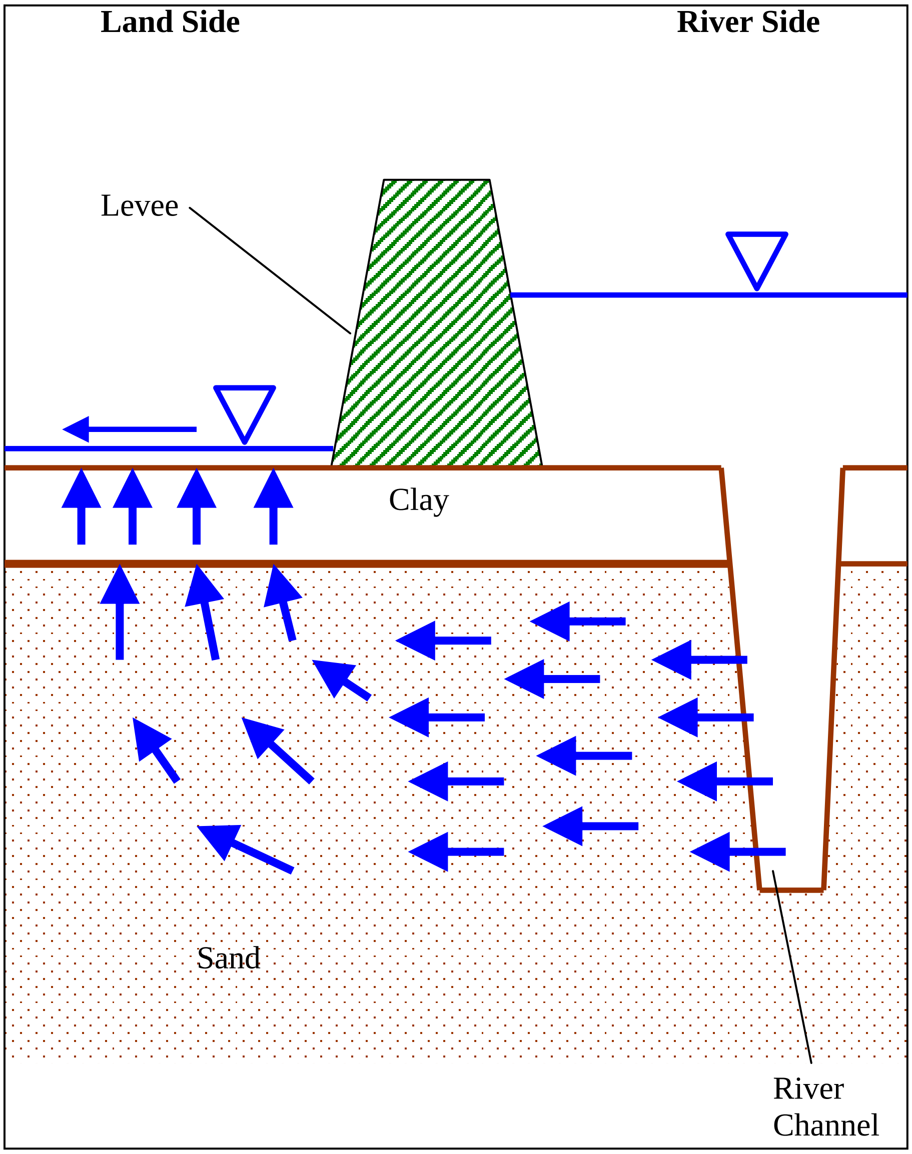

Figure D14. Levee Under Seepage Due to High River.

Levee underseepage is not desirable from a levee stability standpoint, and typically is kept to a practical minimum. Although the rate of seepage may be very low per unit length of levee, the accumulated volume can be significant for a long levee over an extended period of time.

There is no connection for fish between the river and the land side while underseepage occurs. Not only is the levee itself a barrier against fish movement, but the gate is also shut on any culvert through the levee.

To plan an EnviroFish analysis it is necessary first to estimate the amount of seepage, and secondly to include that seepage quantity in a continuous simulation model. One method to estimate seepage quantities is to identify a threshold water surface elevation in the river at which seepage begins on the land side of the levee. This method assumes that the rise in water level on the land side is negligible. For river elevations higher than the threshold, seepage is estimated in units of cubic feet per second per linear foot of levee per foot of river, with the water depth above the threshold elevation. If the daily water surface elevations in the river are independent of the operation of the project on the land side of the levee, then the daily seepage values can be calculated independently and input as time-series flows to the continuous simulation hydrologic model. HEC-RAS unsteady will accept such input, for example. It is also possible to devise a HEC-RAS unsteady model that calculates seepage while performing the overall continuous simulation.

Seepage wells (passive process)

Seepage wells are passive wells intended to allow levee underseepage to occur without damaging the levee. As shown in Figure D-15, the seepage water emerges from the well and accumulates on the land side of the levee. A certain amount of seepage may still emerge through the soil despite the action of the seepage well. Seepage wells may be sources of water for environmental restoration sites, flowing during the normal flood season of the river. The lack of pumping costs and controls is an attractive feature of seepage wells, although several wells may be needed to deliver the desired volume of water. The method for estimating the quantity of seepage via seepage wells and the introduction of the seepage quantities into a hydrologic model are similar to those described for levee underseepage.

HEC-HMS and HEC-RAS

Hydrology and hydraulics are two complementary approaches to describing water movement. Hydrology focuses on the volume and timing of water in movement, and on probability. Hydraulics focuses on the mechanics of water movement. In practice, it is difficult to keep hydrology and hydraulics separate, because the hydrologic aspects of a system must be known to

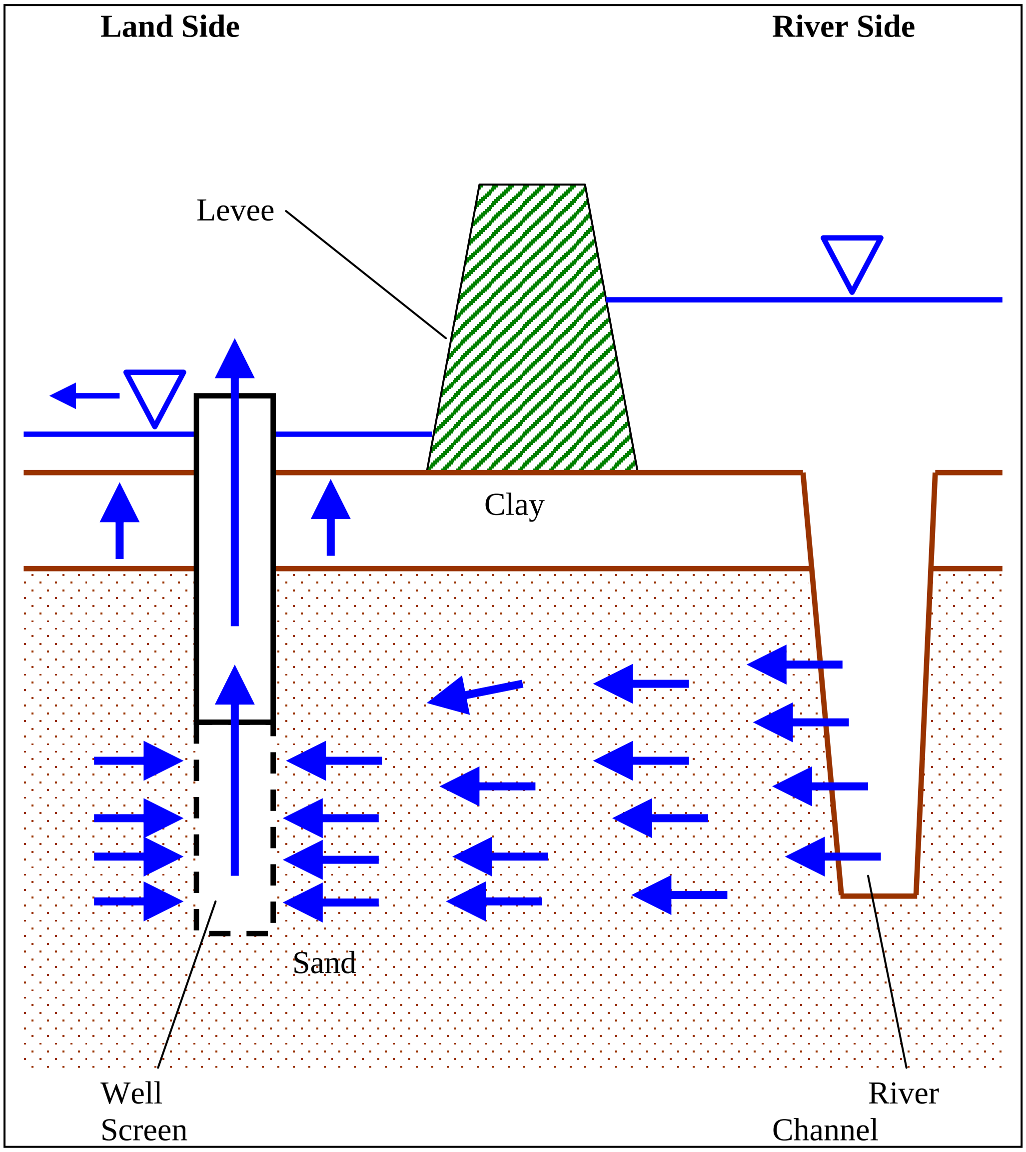

Figure D15. Levee Seepage Well.

characterize its hydraulic aspects, and the hydraulic aspects of a system must be known to characterize its hydrologic aspects. In this section, first the differences between hydrology and hydraulics are described; secondly, the HEC-HMS and HEC-RAS types of software are compared, as an aid in preparing a hydrologic plan for an EnviroFish analysis.

Hydrology

Hydrologic considerations involving an EnviroFish site may include:

1. runoff volume resulting from rainfall;
2. direct rainfall into a pool of water;

3. the varying rate at which runoff water flows into the site (described by the storm hydrograph);
4. evaporation from a pool of water;
5. evapotranspiration from soil;
6. the attenuation of flood hydrographs through a stream reach;
7. inflows and outflows due to seepage;
8. the availability of surface water or ground water to be diverted or pumped to the site;
9. floodplain storage;
10. baseflow; and
11. irrigation withdrawals and releases.

Hydrologic variables include volume, flow, and time. Volumes may be expressed as cubic feet, acre-inch, or acre-foot. Flow is typically expressed not as a velocity (e.g., feet per second), but as a volume rate, (e.g., cubic feet per second). Time scales vary from seconds to decades, depending on the needs of a particular analysis. The description of hydrologic events, both historical and synthetic, is facilitated by division of time into time steps. For example, a flood lasting 3 days, may be modeled by performing computations in time steps of five minutes, and then be described by reporting results in time steps of one hour. Hydrologic models may require short computational time steps to prevent the computations from going awry.

Hydraulics

Hydraulic considerations involving an EnviroFish site may include:

1. the water surface elevation in a stream at a point;
2. the curvature of a flowline along a length of a stream and the water surface elevations at various locations along the flowline;
3. the water surface elevation in a reservoir;
4. the speed of flowing water in a channel;
5. the resistance to flow caused by vegetation;
6. the required size and shape of spillways and culverts; and
7. the energy cost of operating pumps.

Hydraulic variables include area, velocity, flow, and time. Cross sectional flow area may be expressed in units of square feet. Velocity may be expressed in units of feet per second. Flow may be expressed in units of cubic feet per second. The use of time in a hydraulic analysis depends on

whether the flow is considered steady or unsteady. A steady flow hydraulic analysis assumes that flow is known and remains constant. As an example, most FEMA flood insurance studies are based on steady flow hydraulic analyses of the stream and floodplain. The magnitude of the FEMA flood flows are derived from a hydrologic model, such as HEC-HMS. The HEC-HMS flows are then input into a hydraulic model, such as HEC-RAS, set to operate under steady state conditions. An unsteady hydraulic analysis assumes that flow is known, but changes through time. As with a hydrologic analysis, time is divided into time steps. Again, a flood lasting 3 days may be modeled by performing computations in time steps of five minutes, and then reported in time steps of one hour. Like hydrologic models, unsteady hydraulic models may require short computational time steps to prevent the computations from going awry.

+Comparison of HEC-HMS and HEC-RAS

HEC-HMS and HEC-RAS have the capability to be used to model many Enviro Fish sites. HMS has the ability to synthesize rainfall runoff flows, but is limited as a hydraulic software. RAS is a powerful hydraulic software, but cannot synthesize rainfall runoff flows. All flows must be provided to RAS. The significance of this is that HMS can be used as the sole modeling software for simple situations, but more complex situations will typically require the use of both HMS and RAS. HMS and RAS are described below, and a table of features is provided to facilitate comparison between the two software.

HEC-HMS is a hydrologic program, but it is capable of performing limited hydraulic computations, such as the flow over a weir or through a pipe spillway. HMS has the ability to synthesize rainfall-runoff flows in a continuous simulation covering a multi-year analysis period, and to route the flows through a system. HMS can serve as the only modeling software used to model EnviroFish sites with level pools, limited controls, and simple tailwater characteristics. HMS can model flood control pumps also. Although HMS may not explicitly provide for every possible flow source and control that can be encountered in an EnviroFish analysis, an experienced modeler can use available HMS features to simulate many aspects of a site.

HEC-RAS is a hydraulic program, but, in unsteady mode, it is capable of performing flood wave routing through a system. Like HMS, RAS can perform a multi-year, daily continuous simulation. RAS cannot calculate

rainfall runoff flows like HMS, but can accept runoff flow values previously calculated using HMS, and route them through a system. HMS is more powerful than HMS in dealing with complex controls and complex tailwater characteristics. Like HMS, RAS can model flood control pumps. RAS is not limited to modeling level pools, but can calculate curved flowlines throughout an open channel system. An experienced modeler can use RAS to realistically model situations that are not explicitly listed among the software capabilities. If need be, seasonal changes in controls can be modeled in RAS by performing a chain of analyses through each season of a multi-year analysis period.

Table D-1 lists some of the features of HMS and RAS that can be of importance in an EnviroFish analysis. Comparison of these features can be helpful in selecting software to be listed in the hydrologic plan. Table D-1 indicates there is much overlap in the capabilities of the two types of software; however, an experienced modeler is needed to point out the feasibility of using HMS or RAS for a particular task.

Table D-1. Comparison of HEC-HMS and HEC-RAS Features Related to an EnviroFish Analysis.

Feature	HEC HMS 3.4	HEC RAS 4.0 Unsteady
Continuous simulation of rainfall-runoff	X	
Level pool routing	X	X
Culvert hydraulics	X	X
Weir hydraulics	X	X
Gated culverts	X	X
Pump stations (flood control)	X	X
Flowlines		X

Assembling the Hydrologic Plan

The topics described in this appendix facilitate the development of a hydrologic plan for an EnviroFish analysis. The planner needs to consult repeatedly with experienced hydrologic and hydraulic modelers as the overall EnviroFish plan develops. Figure D-16 and Figure D-17 are example worksheets for an EnviroFish hydrologic plan.

Worksheet 1 of 2, shown in Figure D-16, is used to classify the site hydrologically and to list available hydrologic and meteorological data. Under the site classification heading, there are four selections. The

Enviro Fish Hydrologic Plan, Worksheet 1 of 2
Site Classification and Data

Item	Exist	Future w/o Proj	Alt 1	Alt 2
Site Classification				
uncontrolled & dependent tailwater				
uncontrolled & independent tailwater				
controlled & dependent tailwater				
controlled & independent tailwater				
Hydrologic / Meteorological Data				
stage, river, period of record:		---	---	---
stage, landside, period of record:		---	---	---
stage, other: , period of record:		---	---	---
stage, quality--can the data be used as input to Enviro Fish without hydrologic modeling?				
rainfall, period of record:		---	---	---
evaporation, pan, period of record:		---	---	---
other: , period of record:		---	---	---
other: , period of record:		---	---	---
analysis period, beginning year: ending year:	same	same	same	same

Figure D16. Hydrologic Plan Worksheet, Sheet 1 of 2.

Enviro Fish Hydrologic Plan, Worksheet 2 of 2
Hydrologic Software to Use for Continuous Simulation

Control Components & Passive Processes	HEC-HMS	HEC-RAS Unsteady	Other Software	Exist	Future w/o Proj	Alt 1	Alt 2
none (Enviro Fish will use only historical stage data as input)	---	---	---				
runoff, synthesize daily rainfall-runoff							
routing, level pool							
routing, sloping water surface							
gated culvert, flood control only, no seasonal variations							
gated culvert, flood control and seasonal variations in operation and/or holding pool on land side of levee							
flashboard weir, with seasonal variation in crest elevation							
levee under seepage, synthesize daily inflows							
levee seepage wells, synthesize daily inflows							
pumping, flood control, no seasonal control							
pumping, flood control, with seasonal variation in operation							
pumping, water supply wells, with seasonal variation in operation							
other:							

Figure D17. Hydrologic Plan Worksheet, Sheet 2 of 2.

classification that is suitable for existing conditions may not be suitable for the future without project conditions or for project alternatives. Under the data heading, the availability of stage data is documented. The availability of both landside and riverside data should be determined for projects involving a levee. The quality and continuity of the data should be determined. The suitability of the data for direct input to EnviroFish should be determined. Determination of the availability of meteorological data, such as rainfall and evaporation, may be required. Finally, the period of years selected for analysis should be identified, which may be a small subset of the period of record. The reasons for the adoption of the analysis period should be documented.

Worksheet 2 of 2, shown in Figure D-17, is used to identify which types of software will be used to perform specific hydrologic and hydraulic modeling tasks for existing conditions and project alternatives. HEC-HMS and HEC-RAS are the types of software normally used in Corps projects, but other software may be useful for modeling a site. The components and passive processes appropriate for existing conditions may not be appropriate for project alternatives.

Worksheet 1 and Worksheet 2 are examples of hydrologic planning aids. The planner of an EnviroFish analysis should devise worksheets that are appropriate for the site. The process of recognizing the hydrologic setting, collecting and evaluating data, and planning the use of modeling techniques, although time consuming and laborious, is essential for planning an EnviroFish analysis that is feasible, accurate, and defensible.

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14. ABSTRACT

EnviroFish is both a modeling approach and a computer software. As a modeling approach, EnviroFish estimates the value of floodplain habitat suitable for fish reproduction under a given set of hydrologic and hydraulic conditions. As a software, EnviroFish is a Java computer program facilitating the application of the modeling approach. This manual describes both the modeling approach and the software.

The EnviroFish approach integrates hydrology, hydraulics, land use, and empirically based knowledge of fish reproductive strategies in riverine floodplains to predict a biological response to different flooding scenarios suitable for standard federal planning processes. EnviroFish can be used to calculate Habitat Units for specific floodplain habitats, with each habitat providing different values for spawning and rearing fishes. In order of least to most preferred habitats, are agricultural fields, fallow fields, bottomland hardwood forests, and floodplain waterbodies. EnviroFish was initially developed for flood control projects in the lower Mississippi River Valley. However, the approach is applicable to any alluvial river system where floodplain fish spawning habitat is being managed, mitigated, or restored, by determining applicable land use categories and HSIs for representative fish species.

The EnviroFish software is designed to directly accept data in the Corps of Engineers Data Storage System (DSS) file format. EnviroFish calculates ADFA for an array of project alternatives. The user specifies values of hydraulic criteria (flooding depth and duration) for successful spawning and rearing of fishes and also specifies land use categories to calculate ADFA.

This User's Manual discusses the biological basis of EnviroFish, elements of the model, using the software, application considerations, and an example problem.

15. SUBJECT TERMS

EnviroFish	Flood control	Hydraulics
Fish reproduction	Floodplain fish spawning habitat	Hydrology
	HEC Data Storage System (DSS)	Land use

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